

# **Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-102**

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**DEBRIS/ICE/TPS ASSESSMENT  
AND  
INTEGRATED PHOTOGRAPHIC ANALYSIS  
OF  
SHUTTLE MISSION STS-102**


**March 08, 2000**

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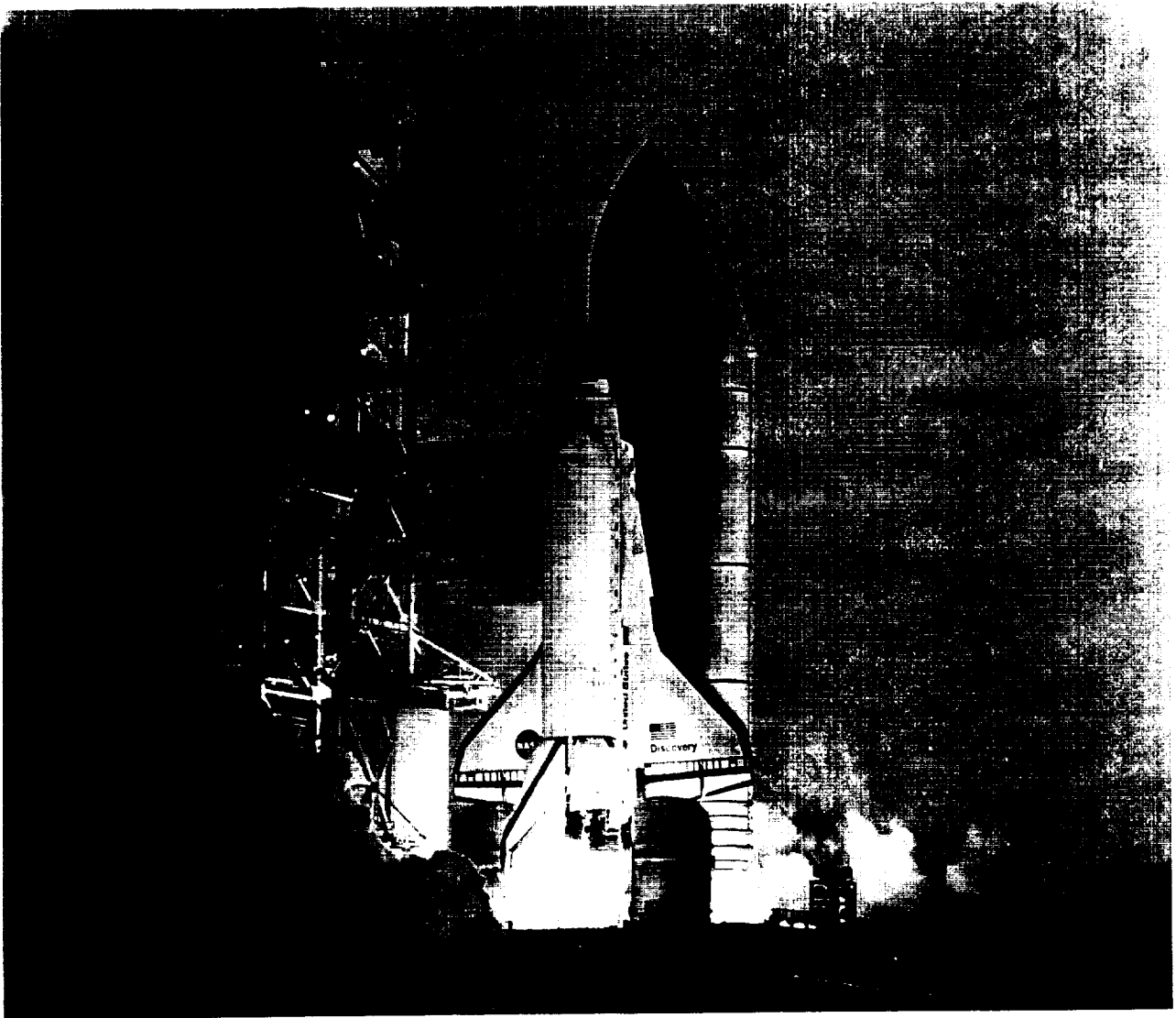
  
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**Photo 1: Launch of Shuttle Mission STS-102**

## **1.0 SUMMARY OF SIGNIFICANT EVENTS**

STS-102 consisted of OV-103 Discovery (29th flight), ET-107, and BI-106 SRB's on MLP-3 and Pad 39B. Discovery was launched at 067:11:42:09.014 UTC (6:42 a.m. local) on 08 March 2001. Landing was at 2:31 a.m. local/eastern time on 21 March 2001.

No significant anomalous events were noted during STS-102 Debris Team surveillance activities.

The Orbiter lower surface sustained 44 total hits, of which 10 had a major dimension of 1-inch or larger, both numbers are well within family. Approximately 14 damage sites (with two larger than 1-inch in length) were located in the area from the nose landing gear to the main landing gear wheel wells. The majority of the hits were around the LH2 umbilical area (22 hits). Most of these damage sites around the ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were well within established family. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites.

### 3.0 LAUNCH

#### 3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 07 March 2001. The walkdown of Pad 39B and MLP-3 included the flight elements OV-103 Discovery (29th flight), ET-107, and BI-106 SRB's. There were no significant SSV discrepancies. All facility items were identified and corrected real time, therefore no potential debris items were entered in OMI S0007 Appendix K for resolution prior to cryoload.

The weather forecast predicted a low of 47 degrees F at L-6 hours (0030 local) along with 71% RH and 10-knot winds at 310 degrees. By T-0, the temperature was expected to be 44 degrees F, 82% RH, and 8-knot winds at 300 degrees. Under these conditions, the computer program SURFICE calculated ET TPS temperature below 32 degrees F during ET cryoload. Also SURFICE predicted positive maximum ice rate that had a potential to accumulate beyond the 1/16-inch maximum ice thickness, attainable only if worst-case moisture (e.g. fog, drizzle, mist runoff) existed. The team advised the Mission Management Team that due to the low humidity frost, no acreage ice would have formed. A contingency plan was developed to send the FIT to the Pad a second time near the T-20 minutes build-in hold if necessary to verify the presence of ice. Based on this rationale no constraint was given for tanking.

#### 3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 08 March 2001 from 0030 to 0245 hours during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There were also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

##### 3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact without any visible discoloration. Ice/frost had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces.

##### 3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement.

##### 3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted below freezing temperatures and frost during ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown.

Ambient conditions – 0030hrs	SURFICE Predictions	IR Surface Readings
47.8 Degrees F.	LO2 ogive 32.77 Degrees F	LO2 Tank 36 – 41 Degrees F
71% RH	LO2 barrel 25.69 Degrees F	
6.3 knots	LH2 upper 21.25 Degrees F	LH2 Tank 32 – 40 Degrees F
266.8 degrees	LH2 lower 32.38 Degrees F	

At T-0 the Ice/Debris Team observed no ice conditions beyond acceptable LCC limits. Protuberance icing previously assessed did not increase. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers until liftoff. At the time of launch, there were no ice accumulations in the "no ice zone".

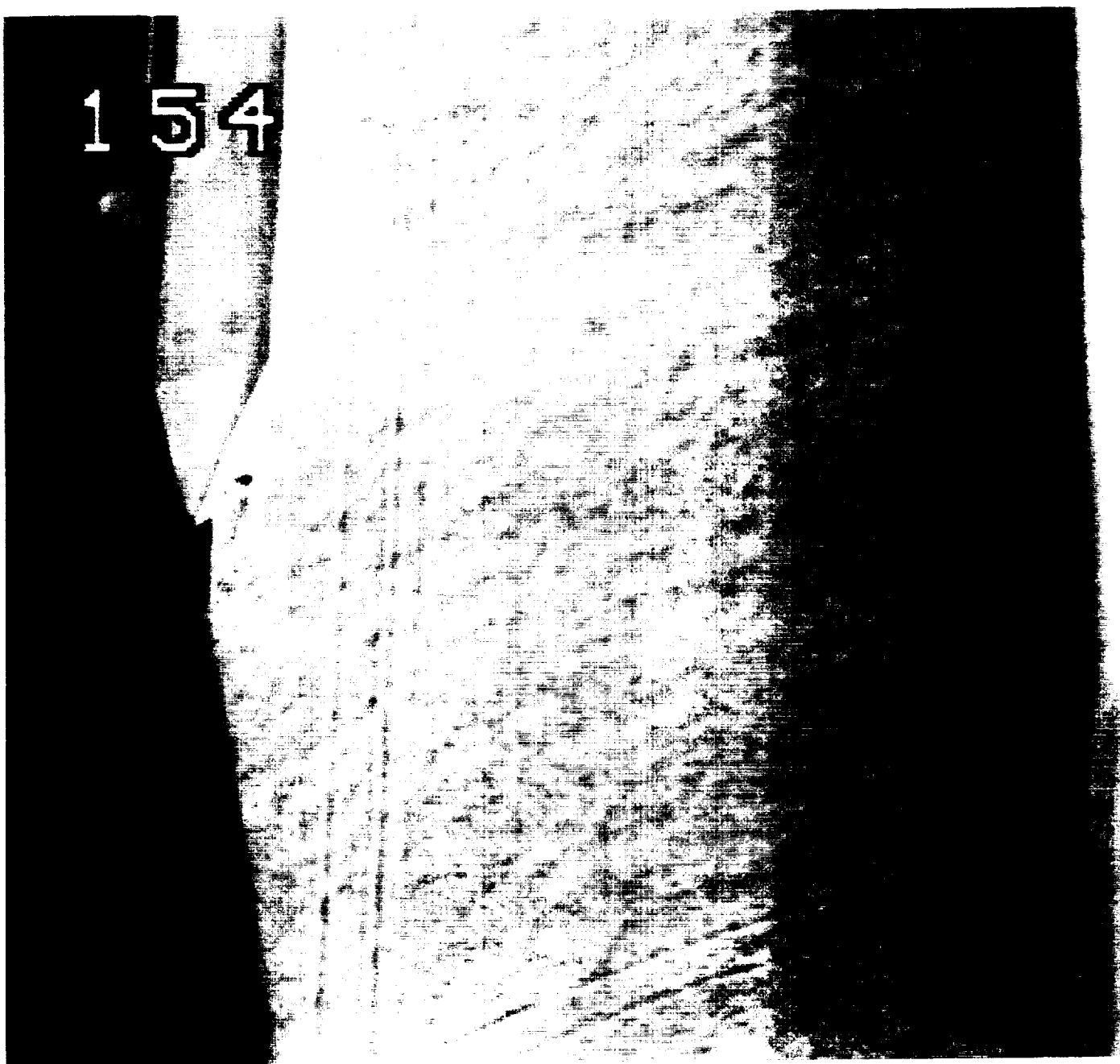
STS-102 was launched at 067:11:42:09.014 UTC (6:42 a.m. local) on 08 March 2001.





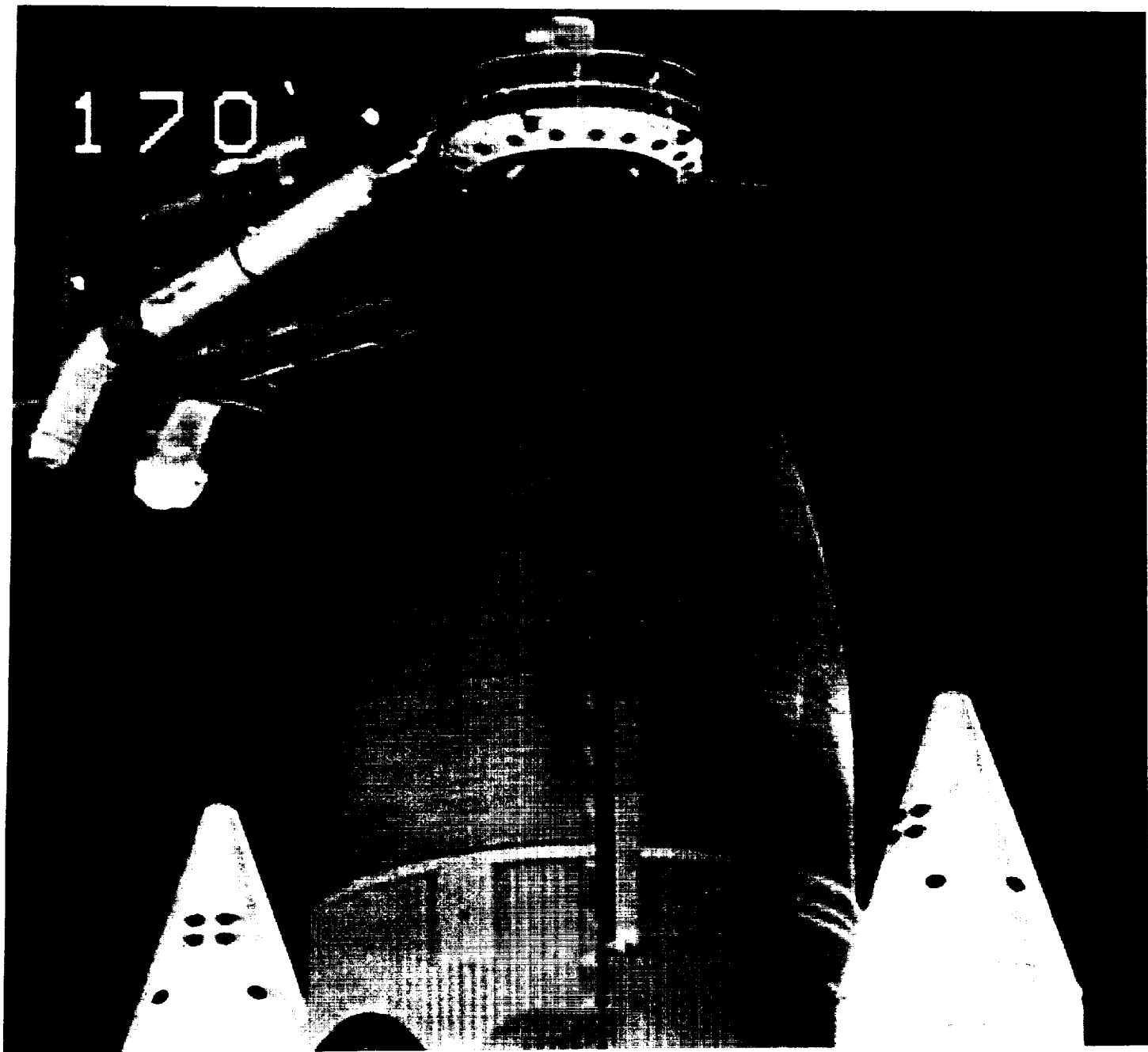
**Photo 2: Frost on LH2 Tank**

Some patches of frost had formed in the +Y+Z quadrant. Surface temperature ranged from 32 to 40 degrees Fahrenheit. Image taken during the FIT walkdown.



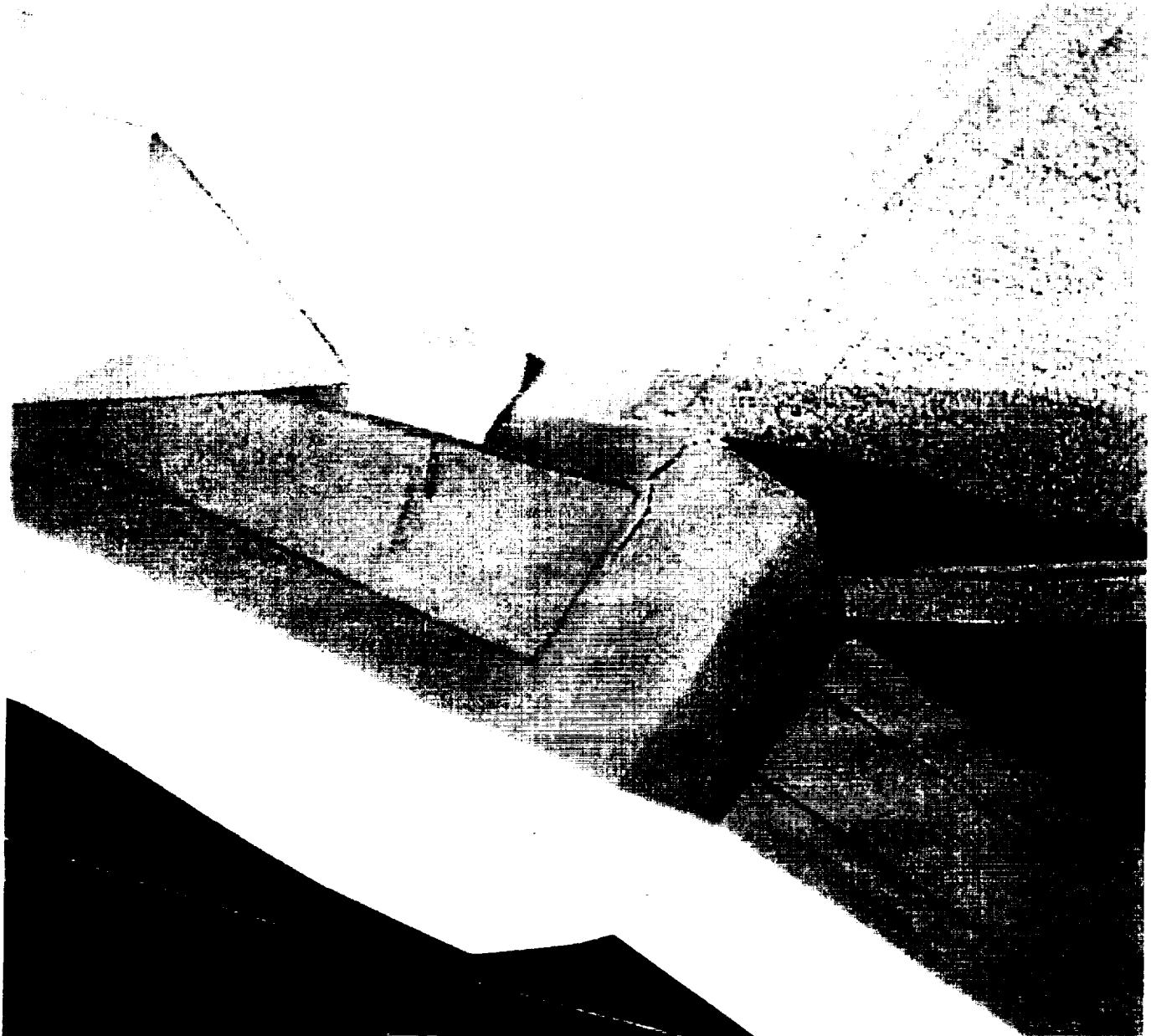
**Photo 3: LH2 Tank Acreage**

During OTV surveillance, after completion of the FIT walkdown, an increase in frost formation was observed on the LH2 tank acreage. This image was captured by OTV camera 154 during the T-20 minutes built-in-hold.



**Photo 4: ET LO2 Tank Forward**

Frost was present on the LO2 tank acreage. Surface temperature ranged from 32 to 41 degrees Fahrenheit. There were no acreage TPS anomalies. This image was captured by OTV camera 170 during the T-20 minutes built-in-hold.



**Photo 5: Cracks in -Y Vertical Strut**

A 8-inches in length and .25 inches wide stress relief crack was observed in the -Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

## **4.0 POST LAUNCH PAD DEBRIS INSPECTION**

The post launch inspection of the MLP-3, Pad B FSS and RSS was conducted on 08 March 2001 from Launch + 2 to 4 hours (0815 to 1015 EST). No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups received from Boeing-Huntington Beach indicated that no SRB holddown stud hang-up had occurred. A HIM card failure prevented Debris team close-up evaluation of the holddown posts, as MLP 0-level was closed (Nitrogen flowing). Evaluation of the 0-level was performed from the FSS. Erosion was typical for the north posts. North holddown post blast covers and T-0 umbilical exhibited typical exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, protective tape layering was partially eroded.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the LO2 bonnet was observed to have closed properly. The MLP deck was in generally good shape.

The GH2 vent line latched in the third of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage, the lip had a dent at the bottom-most location (6 o'clock position). The spool weldment strut had contacted the left-hand latch assembly. The latch was bent slightly. The left-hand side of the GH2 vent line arresting cable was noticeably frayed on the outer surface of the cable.

The OAA appeared to be intact with no evidence of plume impingement.

All slidewire baskets were secured with no evidence of damage.

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage.

Debris findings included:

- Three areas of damage (missing material) were noted on the north flame deflector.
- No flight debris was found on the Pad apron or adjacent grass.
- No unusual debris items were found on the FSS

Overall, damage to the pad appeared to be minimal. Minimal debris was noted on pad apron and FSS.

NASA helicopter was observed west of the pad shortly after the vehicle cleared the tower. (E-52, E-54)

Charring on the ET aft dome was typical. (E-52, E-54, E-207, E-222, E-224)

Umbilical purge barrier baggy material fell shortly after T-0, and later after roll maneuver. (E-54)

Debris particles, possibly purge barrier baggy, instafoam, or ET hydrogen fire detection paper, observed trailing aft near ET LH2 aft dome – between 11:42:24.819 UTC and 11:42:28.914 UTC. (E-54)

Debris particles, probably forward RCS paper cover, were observed trailing aft in the vicinity of the left OMS pod just prior to SRB separation. (E-207)

Debris particle, forward of the -Y thrust strut, seen falling aft shortly after SRB ignition. The length of the debris particle appears to be no more than 11 inches in length and no more than two inches in width. (OTV 109).

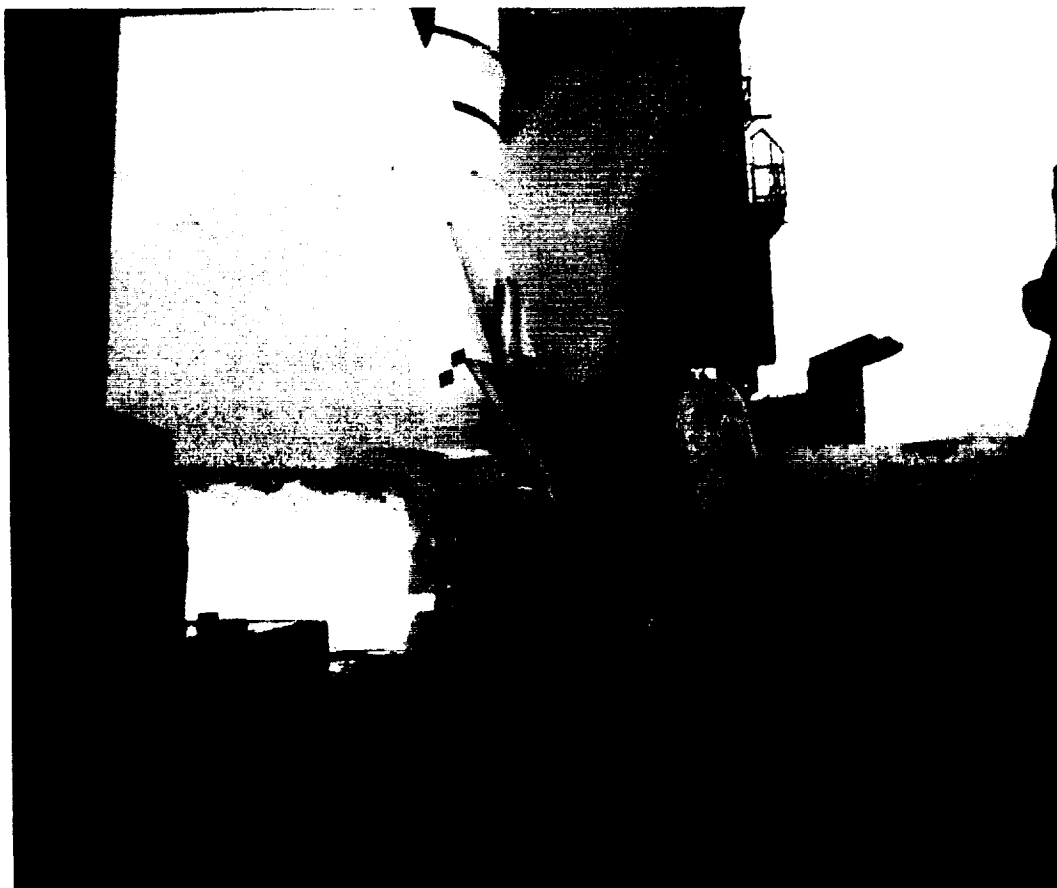
The spray pattern from the LH2 TSM south ROFI became intermittent during SSME startup. Films E-3 and E-20 was reviewed by the pyro system personnel, per their expert evaluation the ROFI performance was found acceptable.

No stud hang up, or ordnance fragments, were observed on any of the SRB hold-down posts.

Multiple pieces of umbilical purge curtain (LH2 and LO2) were observed falling aft during SSME ignition, and during lift off. This is normally observed after the roll maneuver.

Ice particles fell aft crossing field of view past the right hand wing from the RHSRB EB-fitting. No contact with the Orbiter lower surface was noted.

Two distinct flashes accompanied with trailing puffs, occurred in the vicinity of OMS pods. They appeared to be associated with OMS assist burn, shortly after SRB separation. (E-205)



**Photo 8: SRB aft skirt instafoam material broke off during lift off**

Piece of SRB aft skirt instafoam material broke off during lift off due to contact with shoe retainer bracket on hold down post #4 (E-7) (11:42:09.438 UTC). Another piece of instafoam broke off due to contact with hold down post #7 shoe (E-11) (11:42:09.595 UTC)..

## **5.2 ON-ORBIT FILM AND VIDEO SUMMARY**

As expected, no Solid Rocket Booster separation photography was acquired on STS-102. The two 16 mm umbilical well high-speed motion film cameras were not flown on this mission.

The 35mm still images from the LO2 ET/ORB umbilical camera and Crew Hand-Held Still Images, of the External Tank after separation from the Orbiter were received and reviewed at KSC on 27 March 2001. All images were in clear focus. Although the lighting was excellent for areas to the +Y side of the LO2 feedline, the -Y side of the ET was in deep shadow.

No anomalies or significant missing TPS was detected and the ET appeared in excellent condition.

The visible portion of the +Y thrust panel exhibited no divots or anomalies

The red-colored purge seal that normally fits around the EO-3 ball fitting had come loose and floated aft by its tether.

The EO-3 (LO2 side) separation bolt protrusion was noted. Protrusion appeared to be less than EO-3 bolt protrusion observed on STS-106 film. Shuttle Program investigation determined no anomaly for STS-106 bolt extension.

No damage was detected on the LO2 ET/ORB umbilical disconnect, sealing surfaces, or closeout TPS. Typical ablation and divoting was noted on the vertical portion of the umbilical cable tray.

Some small, irregular, white or light-colored objects floating in field of view is believed to be pieces of frozen oxygen or hydrogen.

No anomalies were detected in the LO2 tank acreage. The BSM burn scars were typical.

Normal amounts of TPS erosion and topcoat charring occurred on the forward ogive near the nose cone, but no divots or grooves in the TPS were observed. The composite nose cone was in good condition.

Small amount of TPS erosion/ablation was observed on the forward face of the LH2 PAL ramp.

ET LH2 tank and intertank acreage appeared nominal.

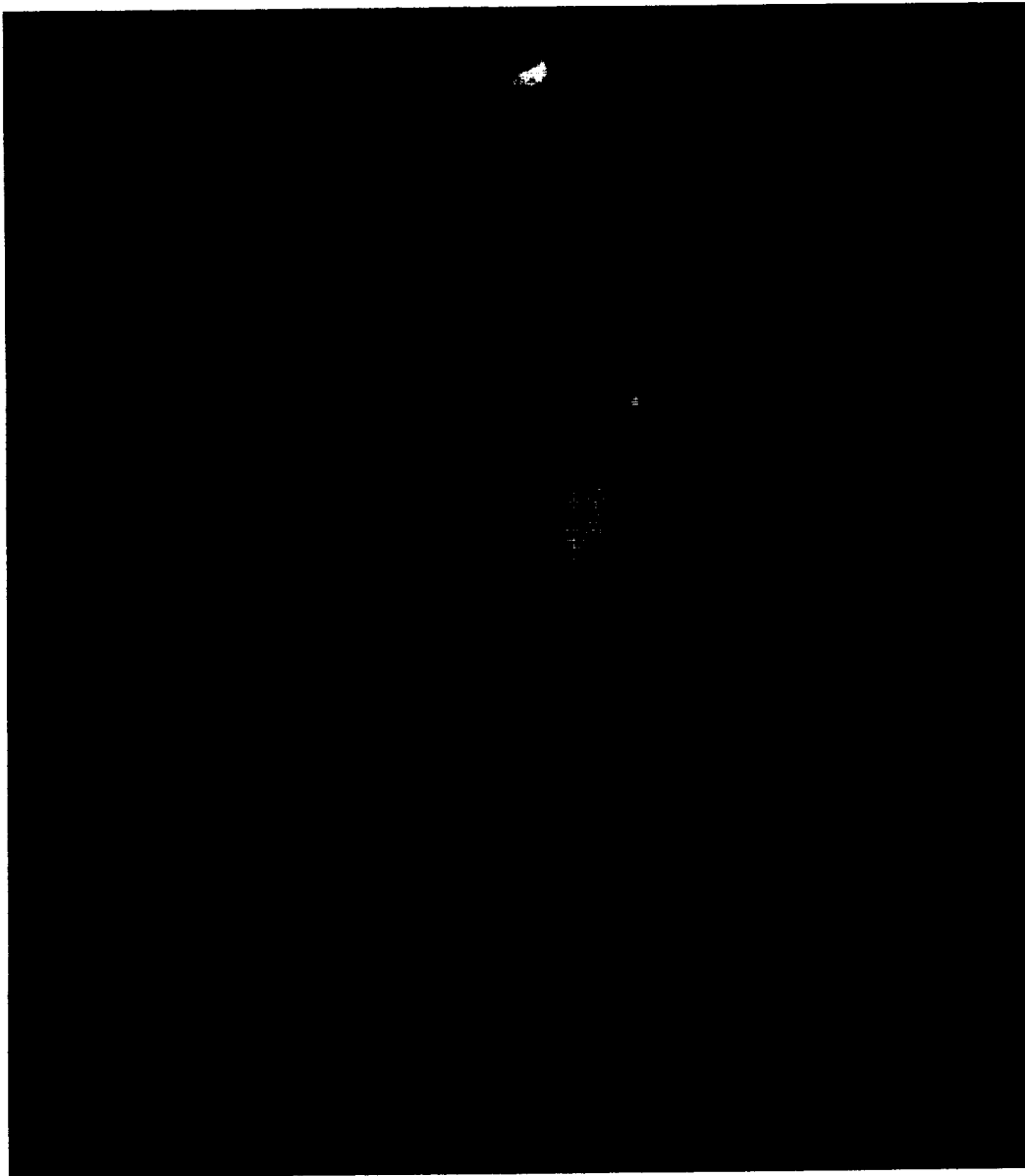
The ablation/erosion of LO2 feedline flange closeouts was typical.

## **5.3 LANDING FILM AND VIDEO SUMMARY**

A total of 17 films and videos, which included eight 35mm large format films and nine videos, were reviewed.

The landing gear extended properly. The right MLG tires contacted the runway first. Drag chute deployment appeared normal. No anomalies were detected from touchdown through rollout. No unusual tile damage was visible in the films.



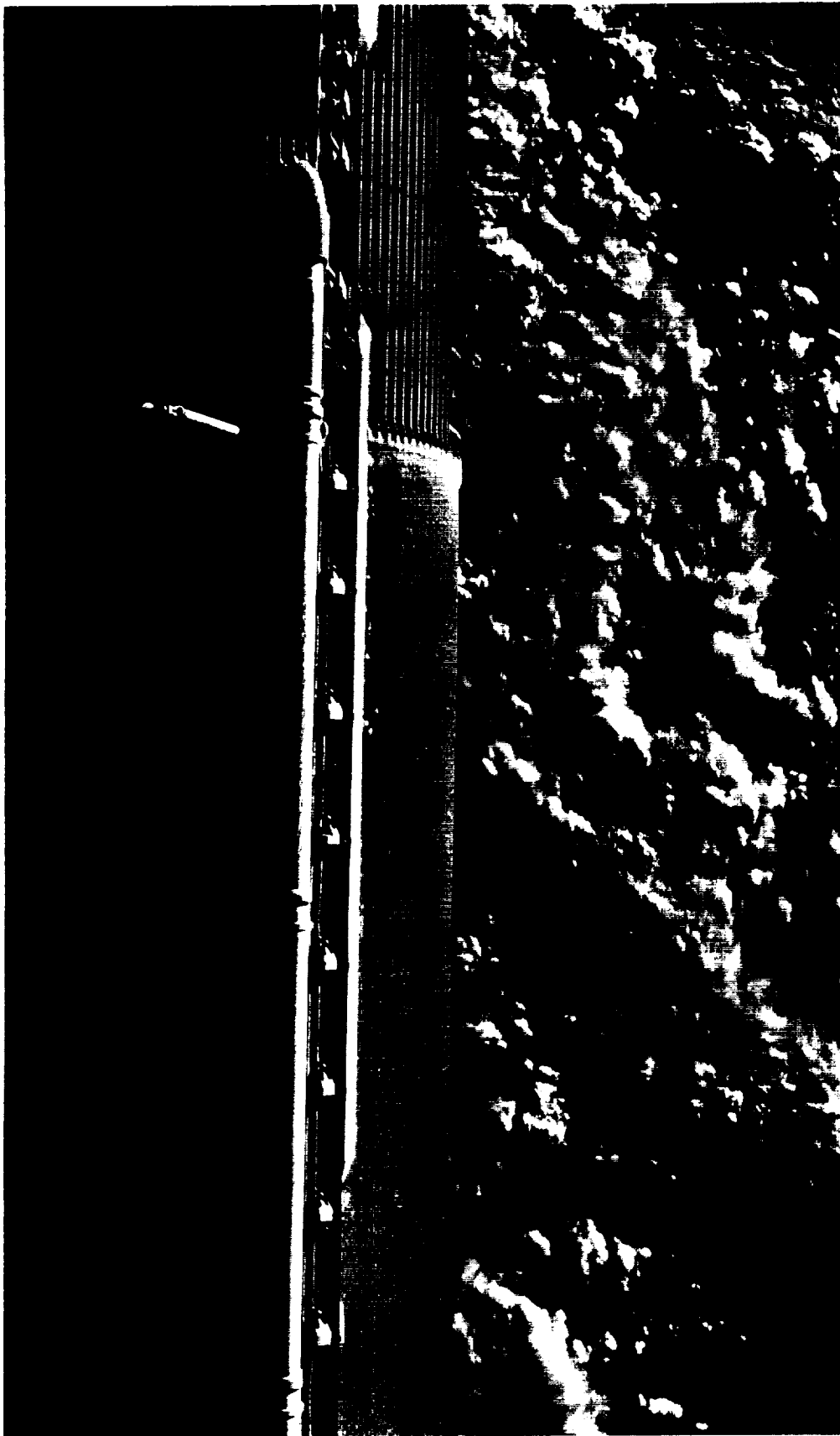


**Photo 11: Astronaut Handheld Camera View of the External Tank**  
No anomalous condition were noticed

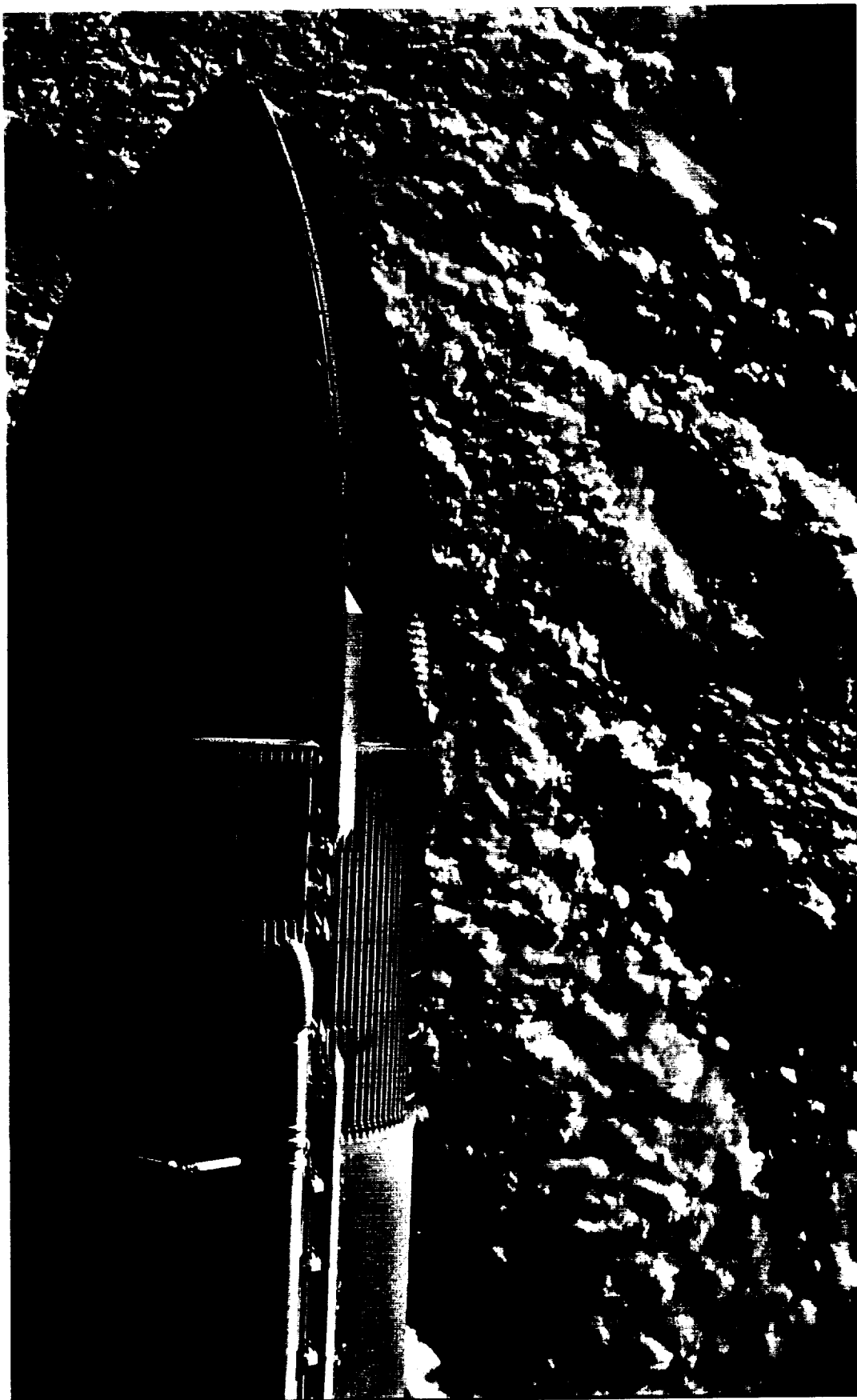


**Photo 12: View of the External Tank after sep**

No anomalous condition was noticed. EO-3 (LO2 side) separation bolt protrusion was observed.



**Photo 13: View of the External Tank after sep**  
No anomalous condition was noticed.



**Photo 14: View of the External Tank after sep**  
No anomalous condition was noticed

## **6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT**

The BI-106 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 12 March 2001. Generally, both boosters were in excellent condition.

The TPS on both frustums exhibited no debonds/unbonds.

All eight BSM aero heat shield covers had fully opened and locked, but two RH covers attach rings had been bent at the hinge by parachute riser entanglement.

The forward skirts exhibited no debonds or missing TPS. The RSS antennae were intact. One pin retainer clip was bent up 90 degrees, but still installed in place.

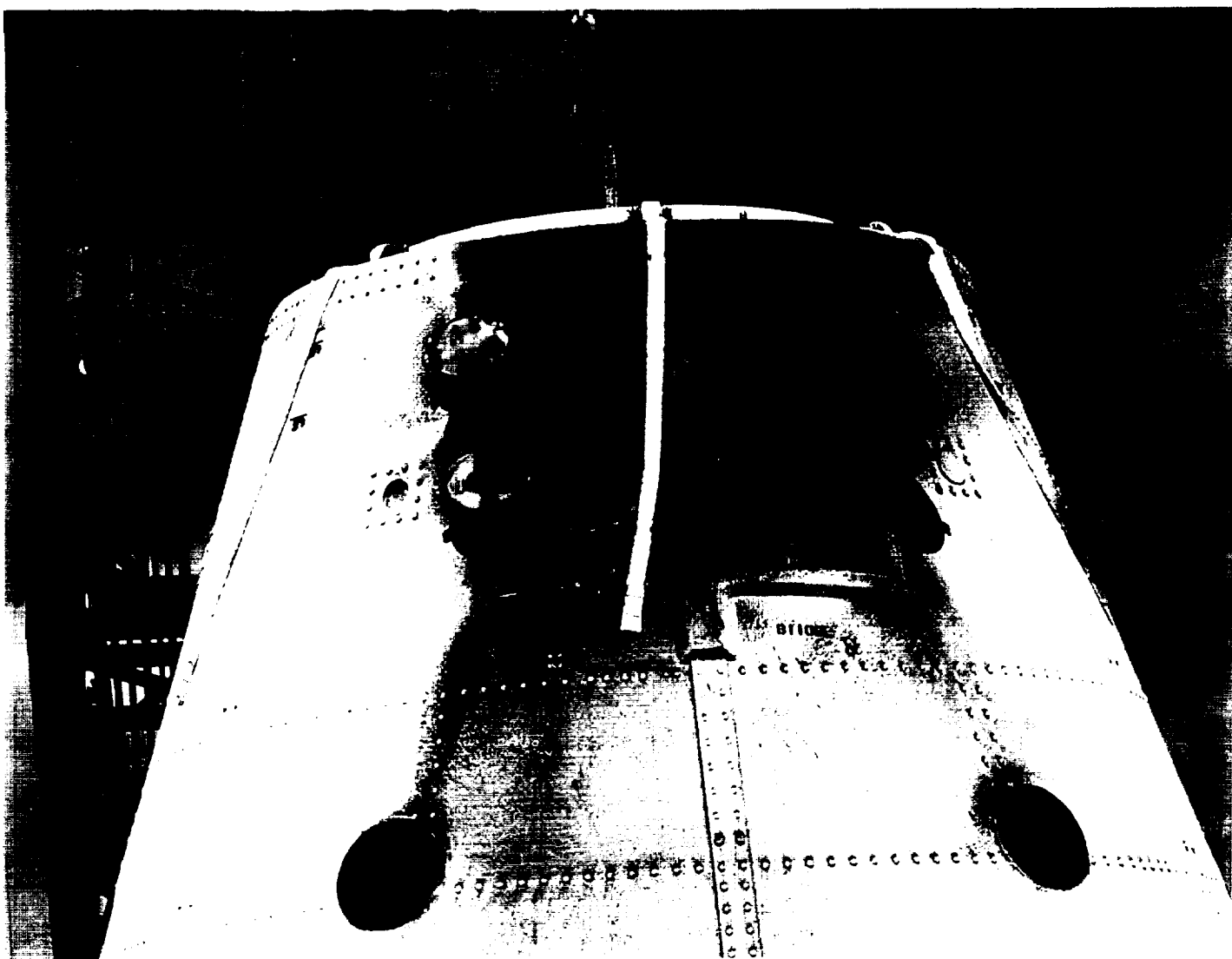
The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were generally in good condition with no unbonds observed.

Separation of the aft ET/SRB struts appeared normal.

Aft skirt external surface TPS was in good condition. Typical blistering of Hypalon paint had occurred on the BTA insulation close-outs and GEI cork runs.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally. No indication of stud hang up was observed.

In summary both SRB's were found in good condition regarding debris assessment.

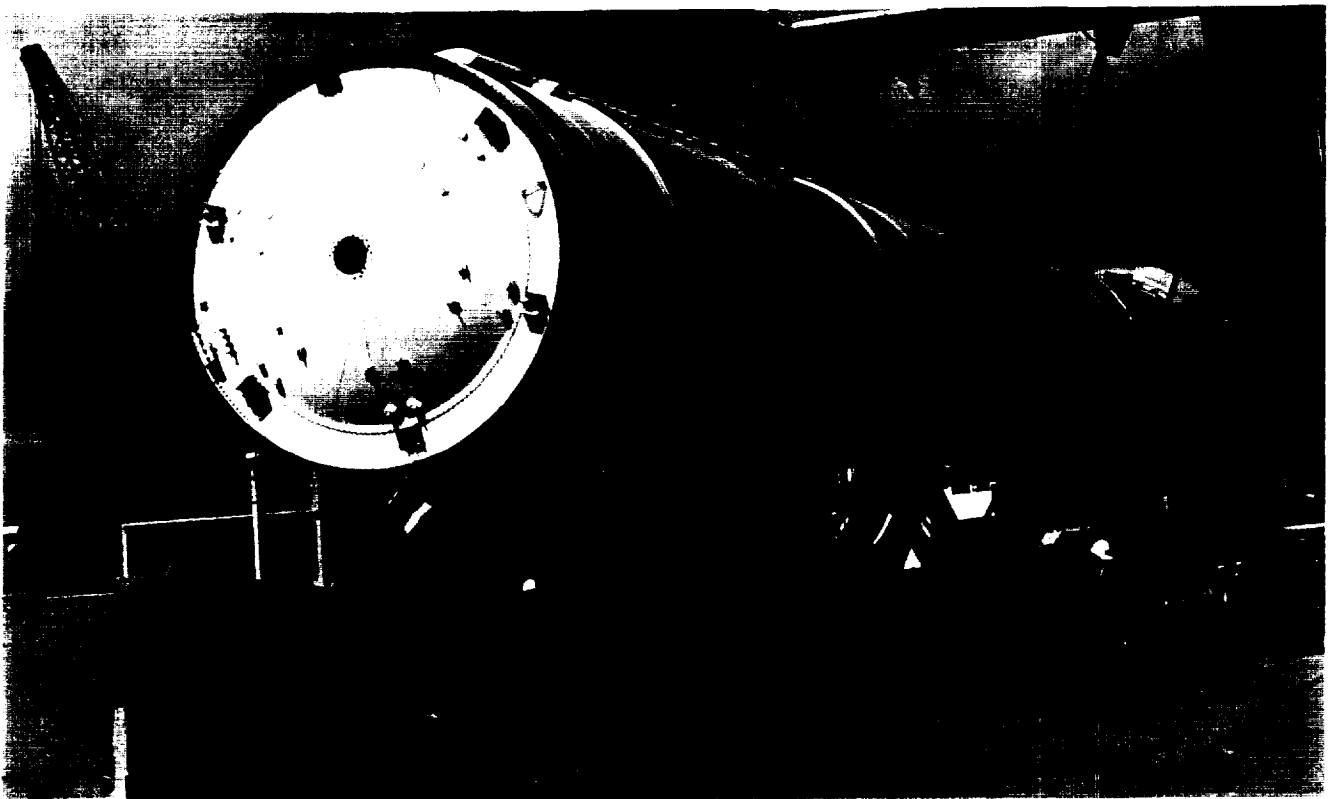
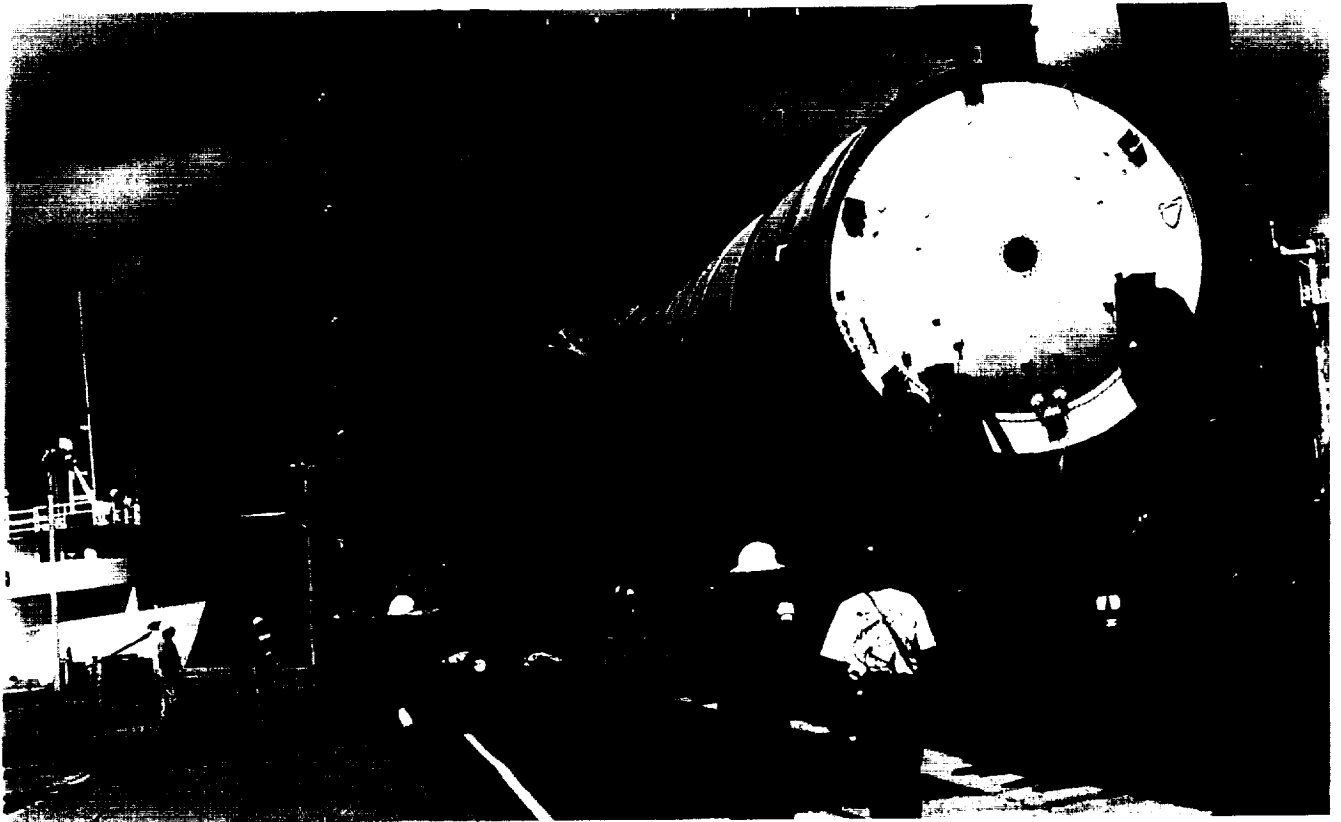


**Photo 12: Frustum Post Flight Condition**

The frustums exhibited no debonds/unbonds or missing TPS.  
All eight BSM aero heat shield covers had locked in the typical opened position.



**Photo 13: Forward Skirt Post Flight Condition**  
The forward skirts exhibited no debonds or missing TPS.



**Photo 14: SRB Post Flight Condition**

Both SRB's were found in good condition regarding debris assessment



## 7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 2:31 a.m. local/eastern time landing on 21 March 2001, a post landing inspection of OV-103 Discovery was conducted at the Kennedy Space Center on SLF runway 15 and in Orbiter Processing Facility bay 2. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 100 hits of which 15 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shields attributed to SSME vibration/acoustics and exhaust plume recirculation.

The following table lists the STS-102 Orbiter damage hits by area:

	<u>HITS &gt; 1-inch</u>	<u>TOTAL HITS</u>
Lower Surface	10	44
Upper Surface	0	0
Window Area	4	44
Right Side	0	4
Left Side	1	3
Right OMS Pod	0	1
Left OMS Pod	0	4
TOTALS	15	100

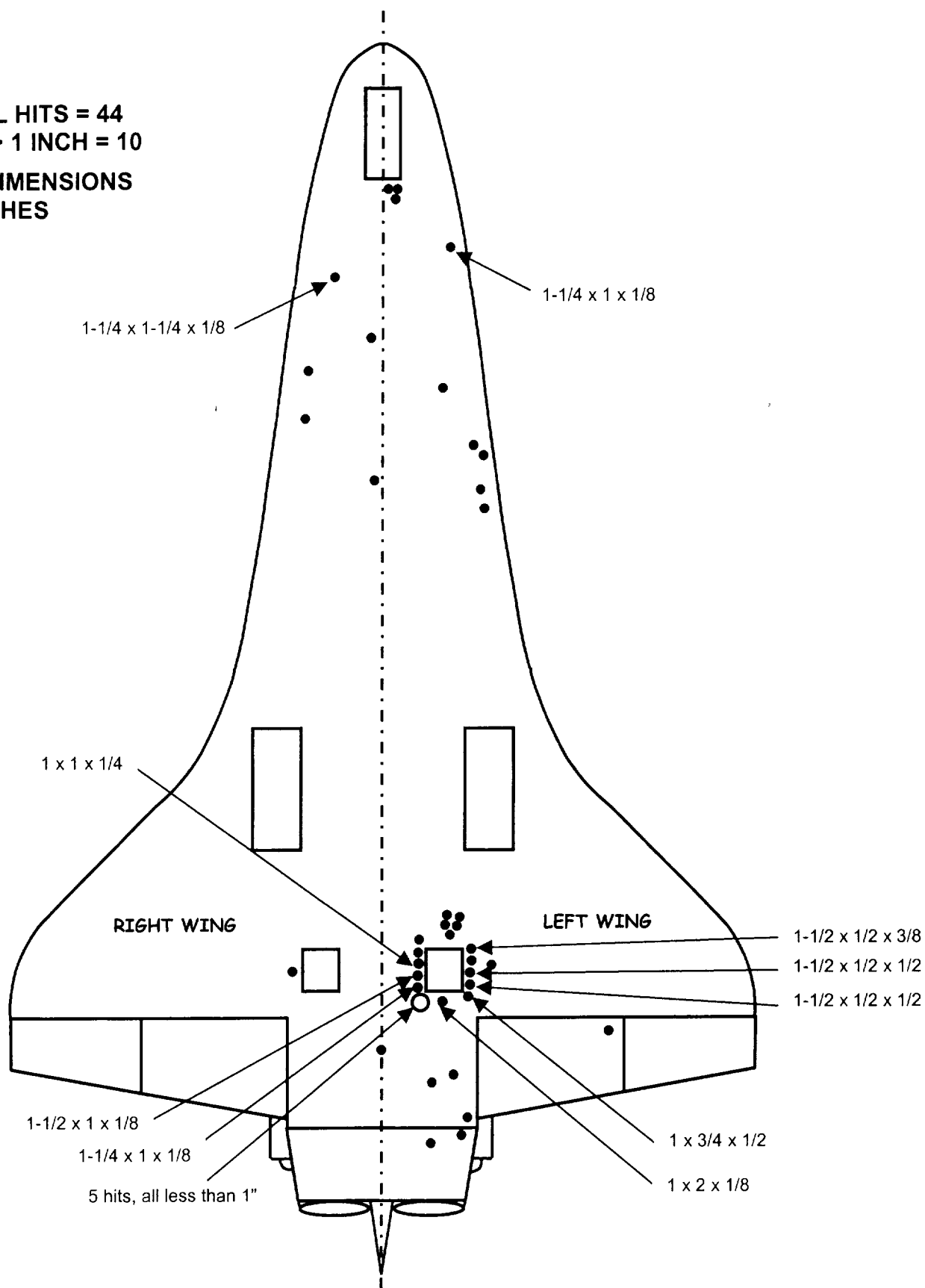
The Orbiter lower surface sustained 44 total hits, of which 10 had a major dimension of 1-inch or larger, both numbers are well within family. Approximately 14 damage sites (with two larger than 1-inch in length) were located in the area from the nose landing gear to the main landing gear wheel wells. The majority of the hits were around the LH2 umbilical area (22 hits). Most of these damage sites around the ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft. The ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites.

The largest lower surface tile damage site, located inboard of the LH2 umbilical, measured 1-inches long by 2-inches wide by 0.125-inches deep. A combination of umbilical ice and/or umbilical purge barrier material could have been the cause of this damage site.

Left hand RCC panel # 10 has a large damage at the leading edge, below apex curve, adjacent to the T-Seal. The damage was 2.0 inches long by .120 inches wide by .100 inches deep. Carbon substrate was exposed. The same panel also had what appeared to be a surface degradation in the middle lower region of panel that is approximately .5-inch diameter. Further investigation determined that the panel 10L damage was caused by subsurface oxidation across the coating-substrate interface and not by a debris impact.

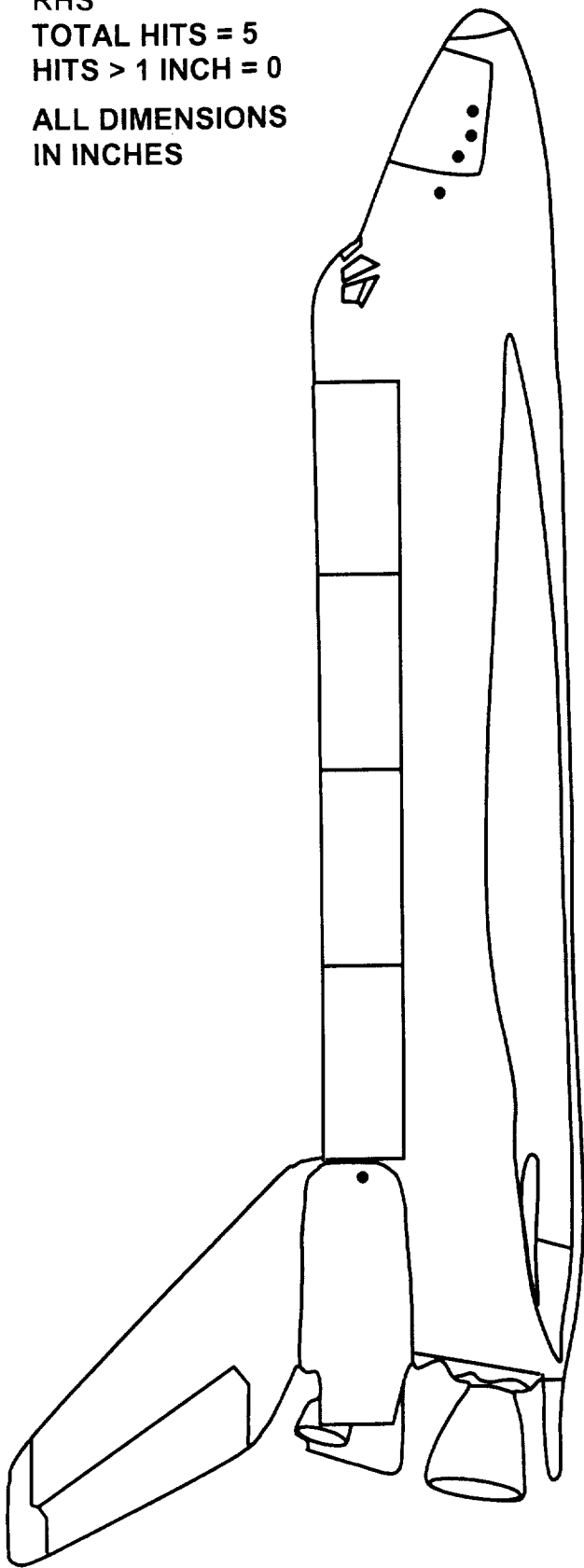
The landing gear tires were reported to be in good condition. There was no ply under cutting on the main landing gear tires.

**TOTAL HITS = 44**  
**HITS > 1 INCH = 10**  
**ALL DIMENSIONS**  
**IN INCHES**

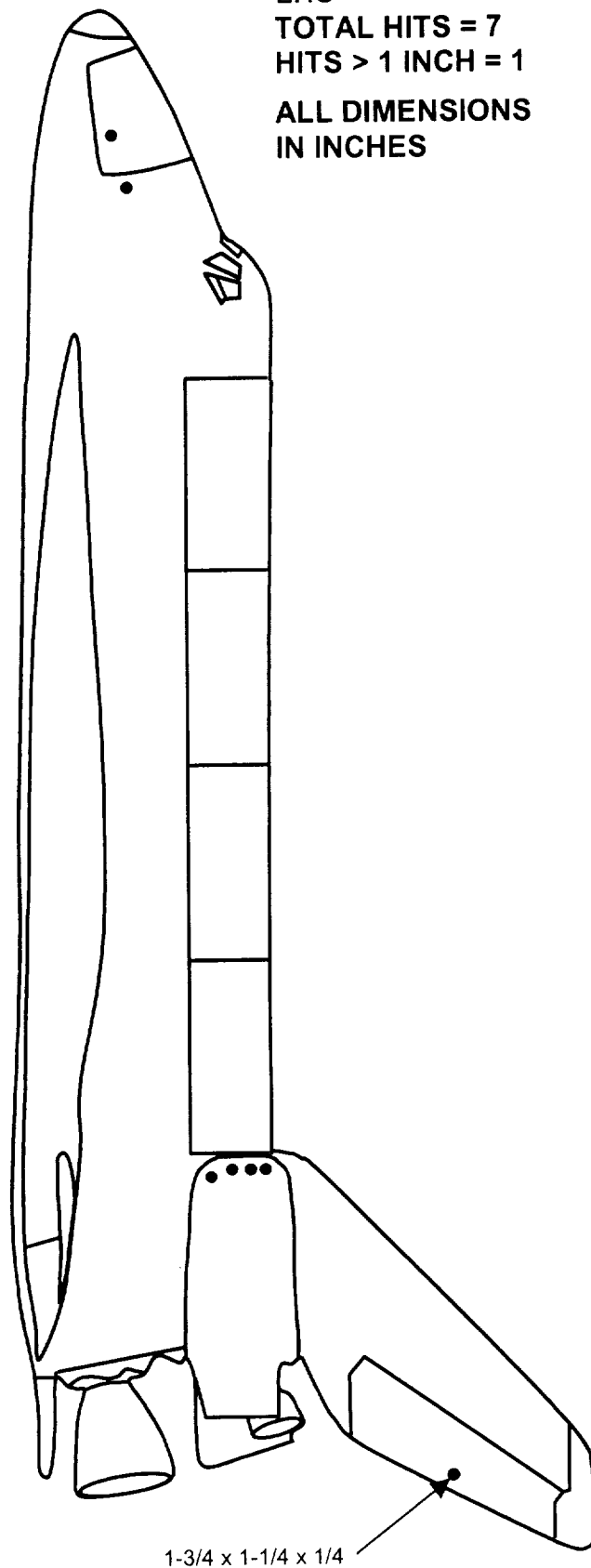


**Figure 1: Orbiter Lower Surface Debris Damage Map**

RHS  
 TOTAL HITS = 5  
 HITS > 1 INCH = 0  
 ALL DIMENSIONS  
 IN INCHES

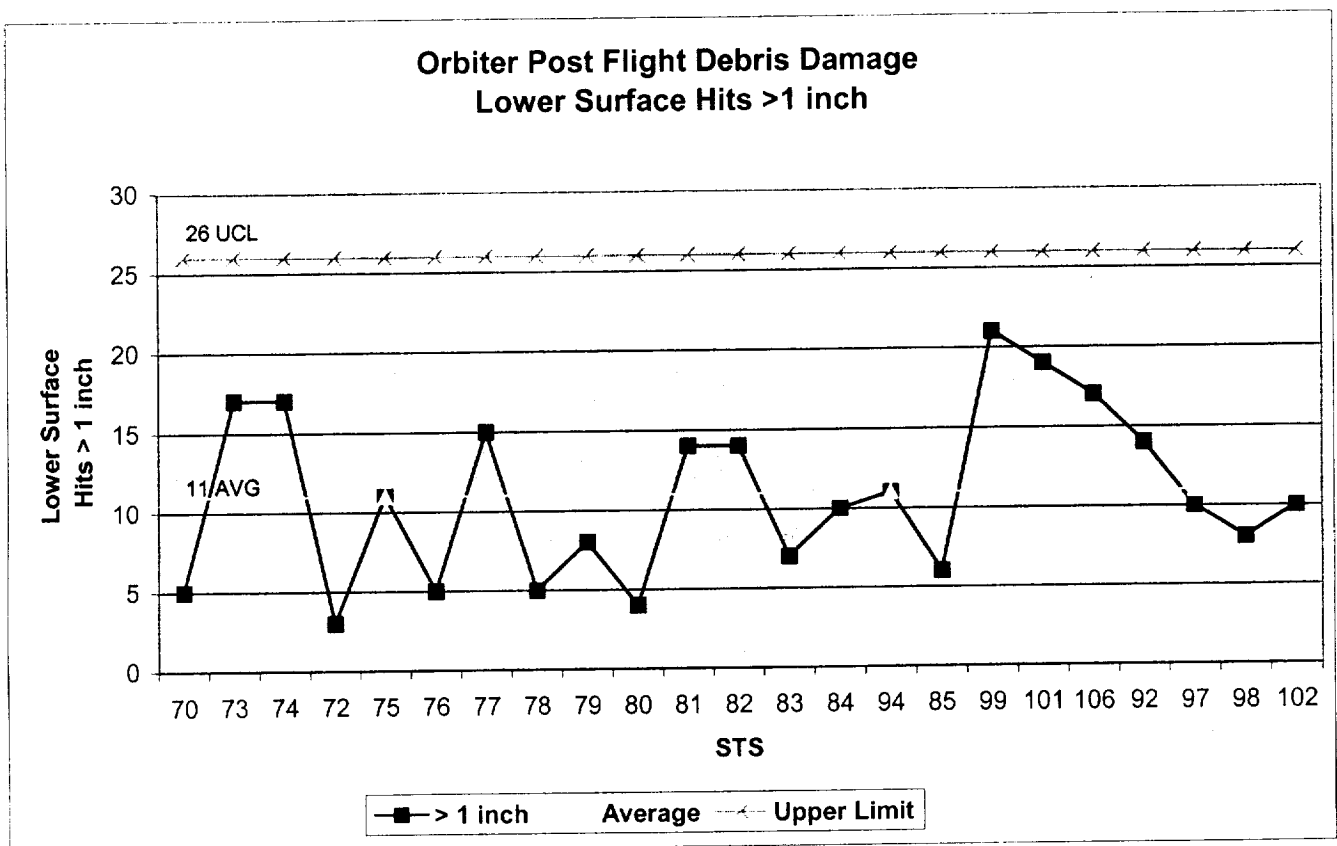
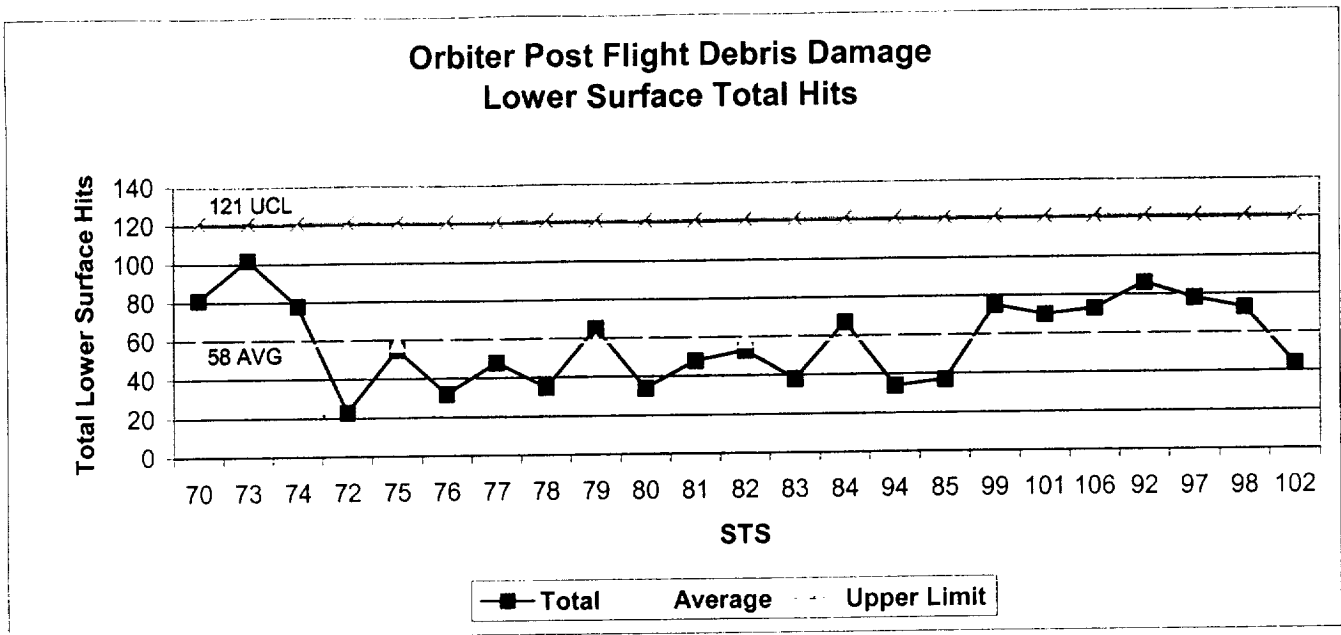


LHS  
 TOTAL HITS = 7  
 HITS > 1 INCH = 1  
 ALL DIMENSIONS  
 IN INCHES

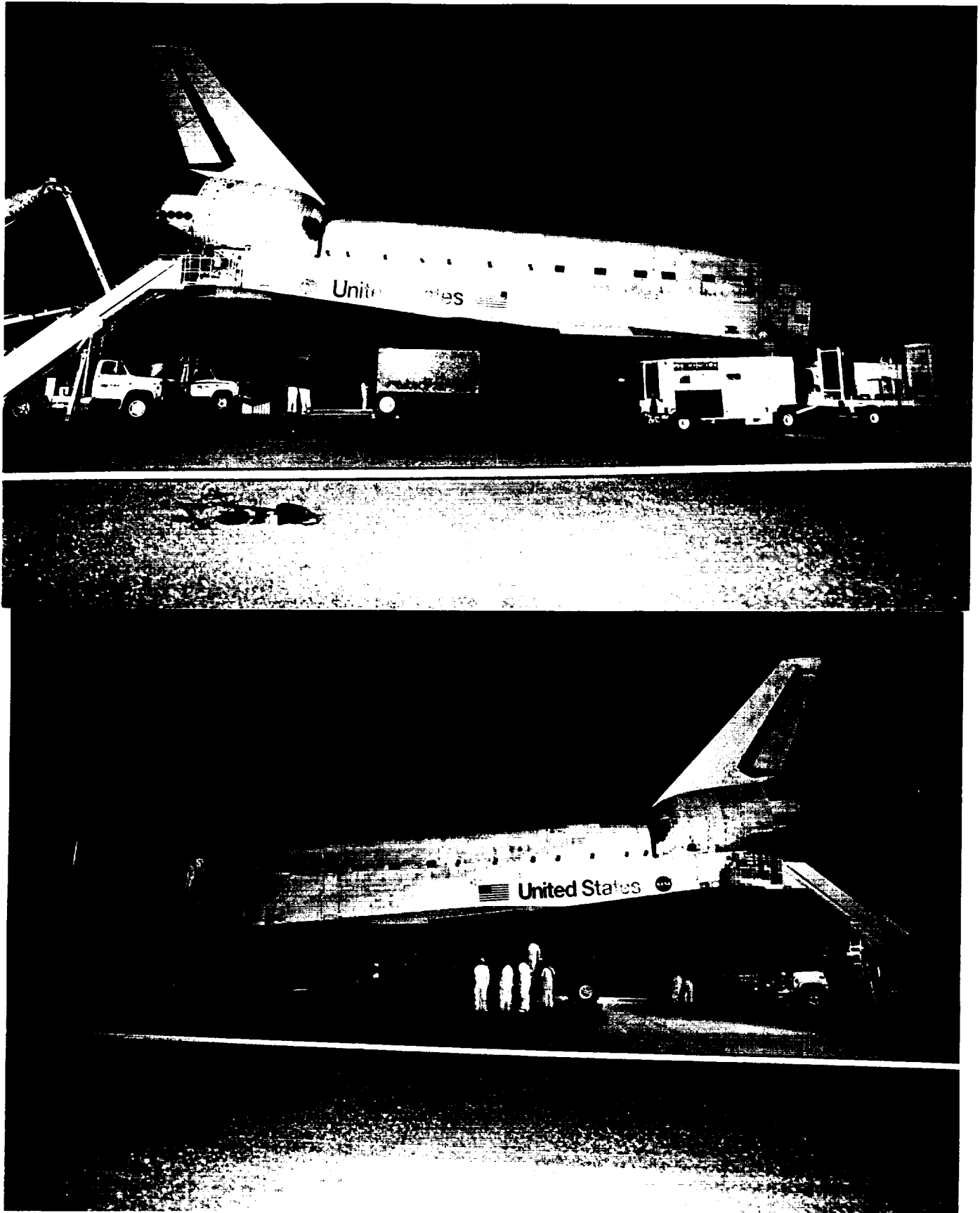


1-3/4 x 1-1/4 x 1/4

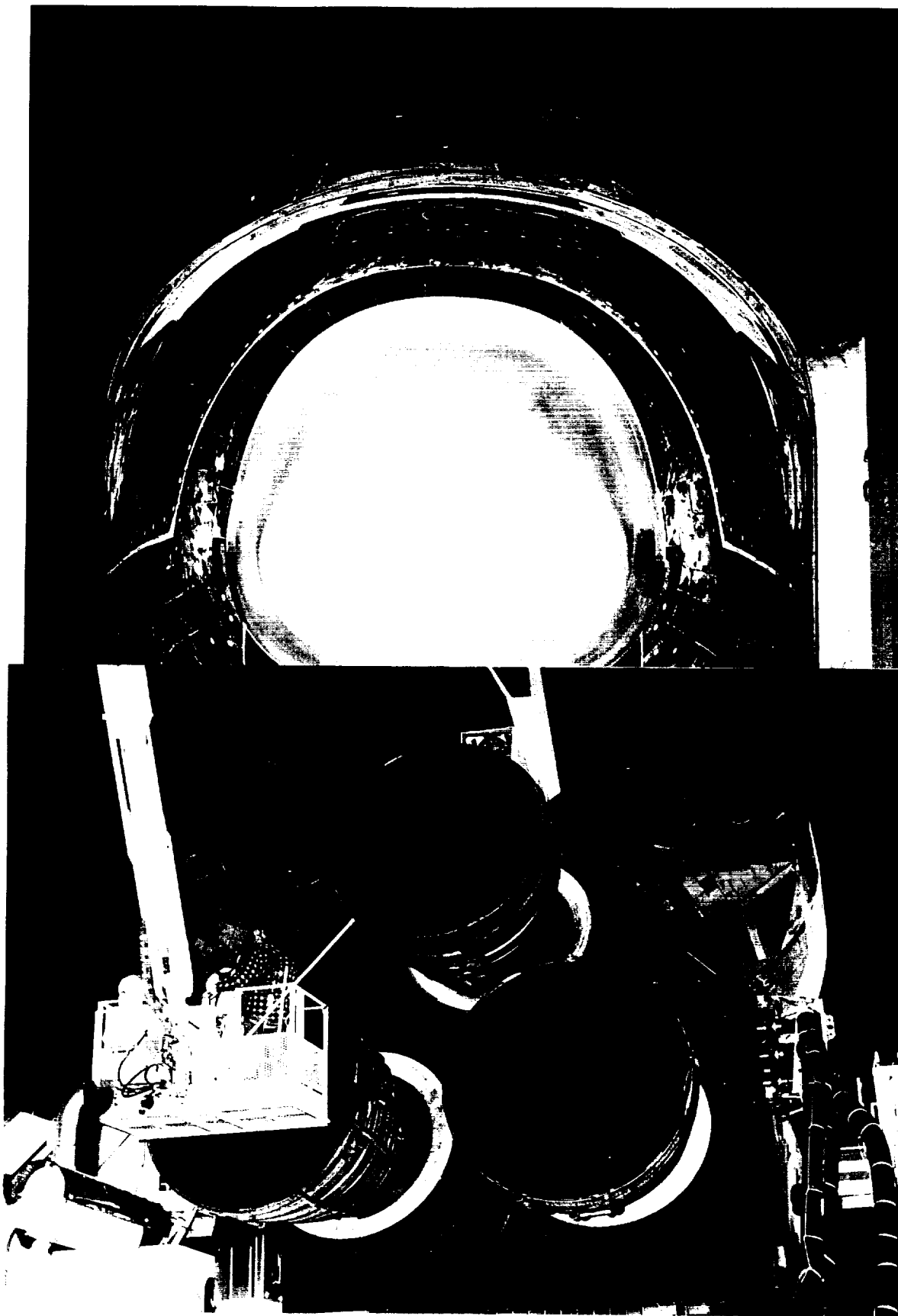
**Figure 3: Orbiter Right/Left Sides Debris Damage Map**



**Figure 5: Control Limits for Lower Surface Hits**

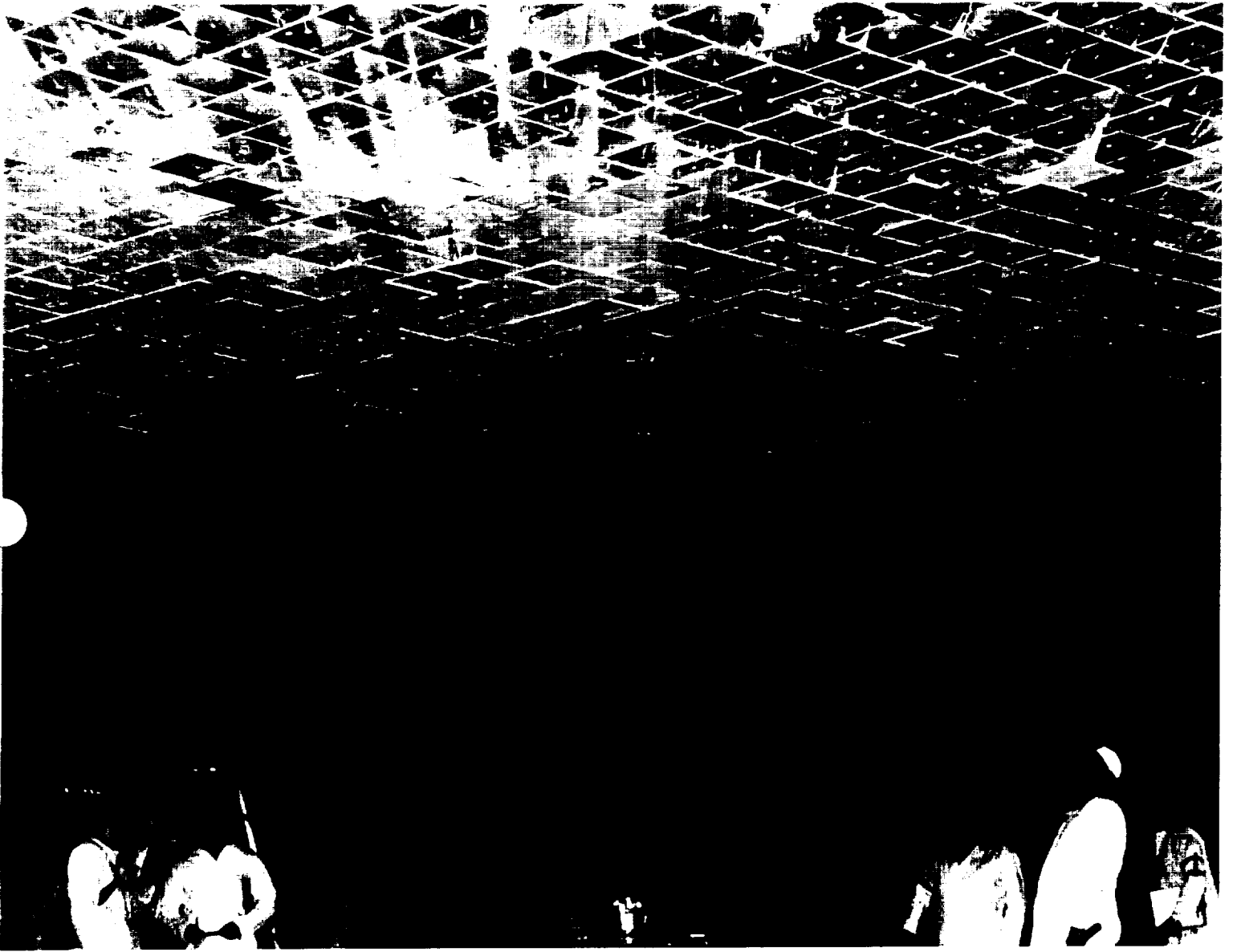


**Photo 16: Overall View of Orbiter Sides**



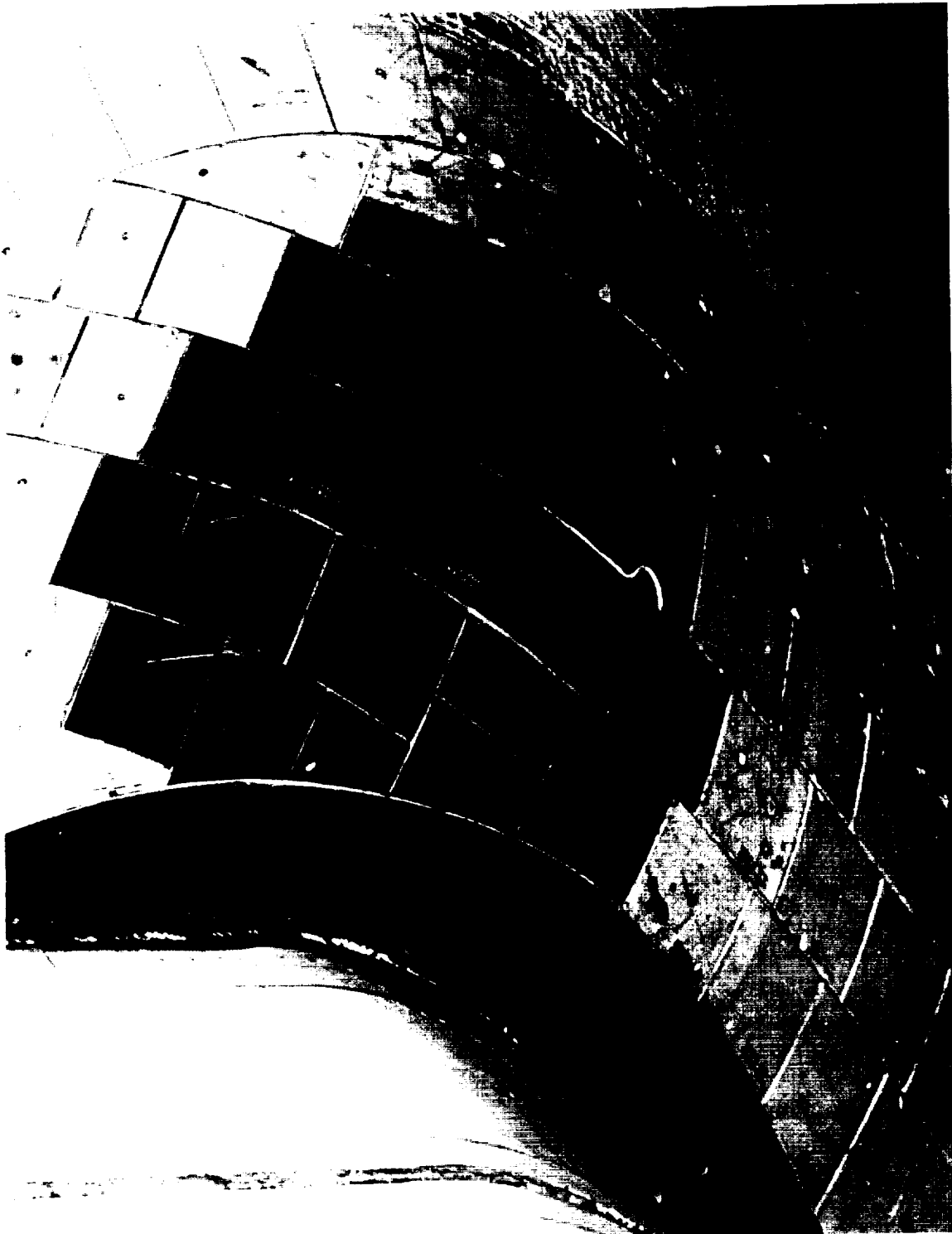
**Photo 17: Windows and Base Heat Shield**

Damage sites on the window perimeter tiles were more than usual in quantity. Less than usual amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in excellent condition.



**Photo 18: Damage to Lower Surface Tiles**

The orbiter lower surface sustained only 44 total hits. Both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were well within established family



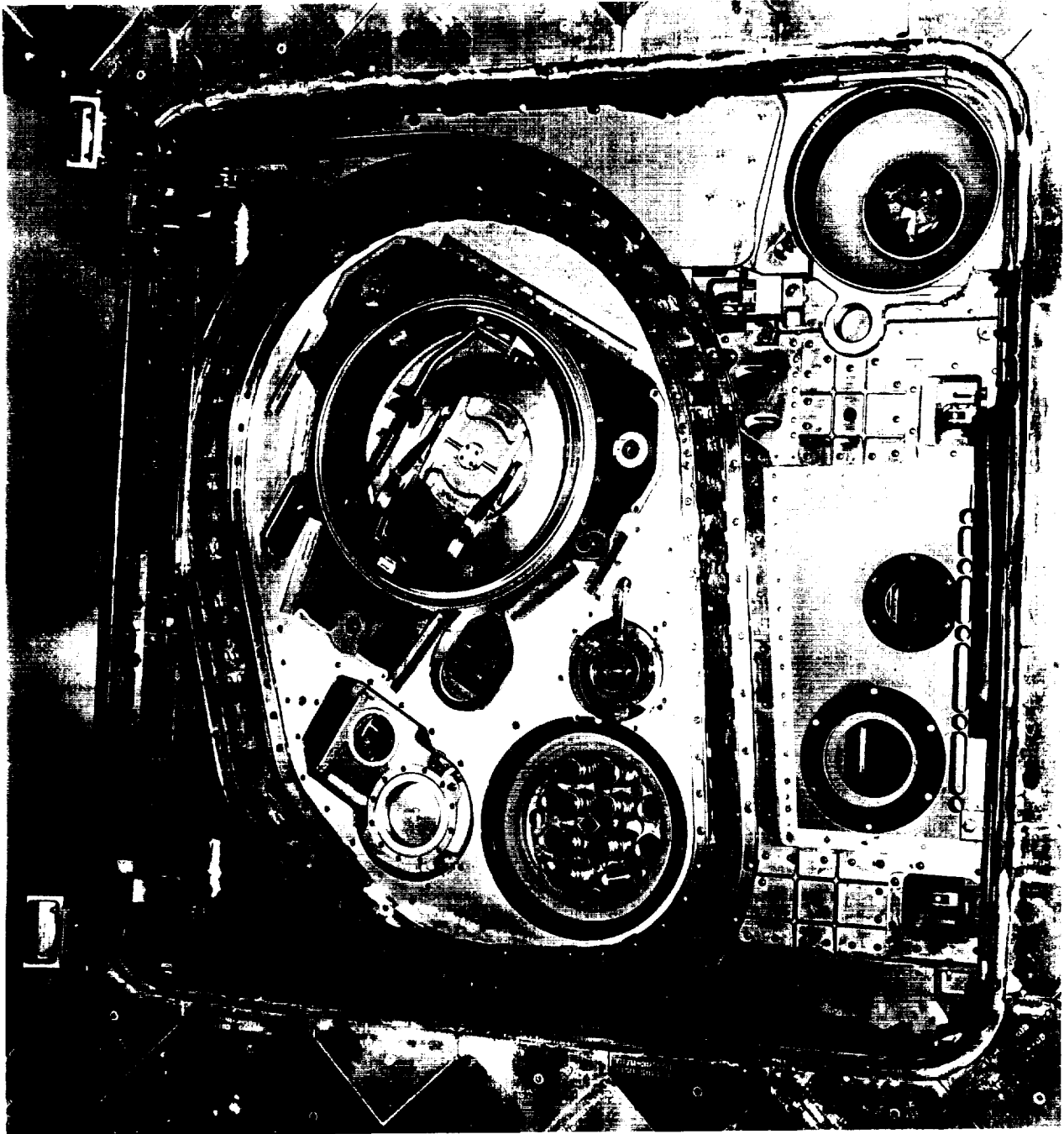
**Photo 19: R/H OMS pod**

One protruding tile gap filler material was found on the R/H OMS pod, approximately 2 inches long.





**Photo 20: LO2 ET/ORB Umbilical**



**Photo 21: LH2 ET/ORB Umbilical**

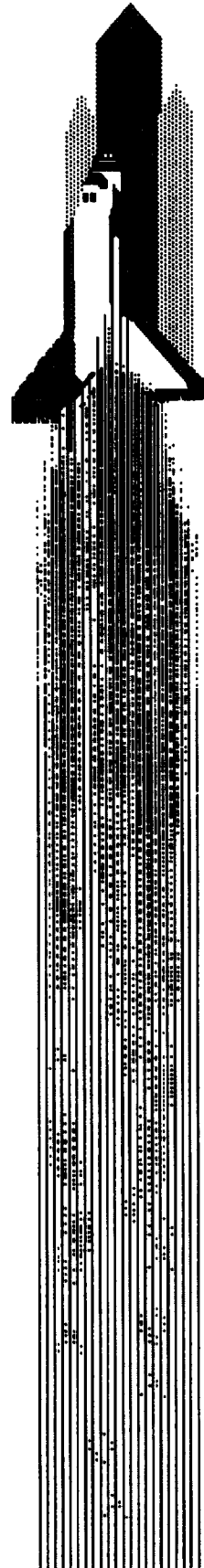
## **APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY**



## **Space Science Branch**

# **STS-102 Summary of Significant Events**

**April 23, 2001**





## Space Shuttle

# STS-102 Summary of Significant Events

Project Work Order - SN3CS

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## **STS-102 (OV-103) Film/Video Screening and Timing Summary**

The landing touchdown appeared normal. The drag chute deploy sequence appeared normal on the landing imagery. Using available video including NASA-Select, no anomalous events were seen during the Orbiter approach, landing, and landing rollout.

Post landing, a sink rate analysis of the STS-102 main landing gear was performed for the main gear touchdown. See Section 2.5.

According to the pre-mission agreement, the STS-102 landing films were not screened due to budgetary constraints.

## **Summary of Significant Events**

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### **2 Summary of Significant Events**

#### **2.1 KSC, JSC, MSFC Film / Video Analysis Teams Consolidated Film Review Reports**

No anomalous events were noted during the screening of the STS-102 launch and landing films. No anomalies were reported in the Launch +4 day or the Landing +3 day KSC, JSC, MSFC Film / Video Analysis Teams Consolidated Film Review Reports.

#### **2.2 Other Launch Observations**

##### **2.2.1 Debris from SSME Ignition through Liftoff**

A small, dark-colored unidentified piece of debris was seen falling aft along the right side of the RSRB before SSME ignition. It is possible that this debris was carried with the FSS deluge water by the northwest winds. (Camera E5)

Similar to previous missions, multiple pieces of ice debris and vapors were seen falling from the ET/Orbiter umbilicals along the -Z side of the body flap during SSME ignition through liftoff. Umbilical ice debris was seen to contact the Orbiter LH2 umbilical well doorsill during SSME ignition (11:42:06.12 UTC). This event has been seen on previous missions. No damage to the launch vehicle was detected. (Cameras OTV109, OTV154, OTV161, OTV163, E1, E5, E17, E31, E34, E54)



Figure 2.2.1 (A) Large Flexible Debris Near LH2 Umbilical Prior to Liftoff

A large piece of light-orange-colored flexible debris was seen falling from below the LH2 umbilical prior to lift off (11:42:07.3 UTC). This debris may have been a piece of umbilical well purge barrier material. (Camera OTV154)



## Summary of Significant Events

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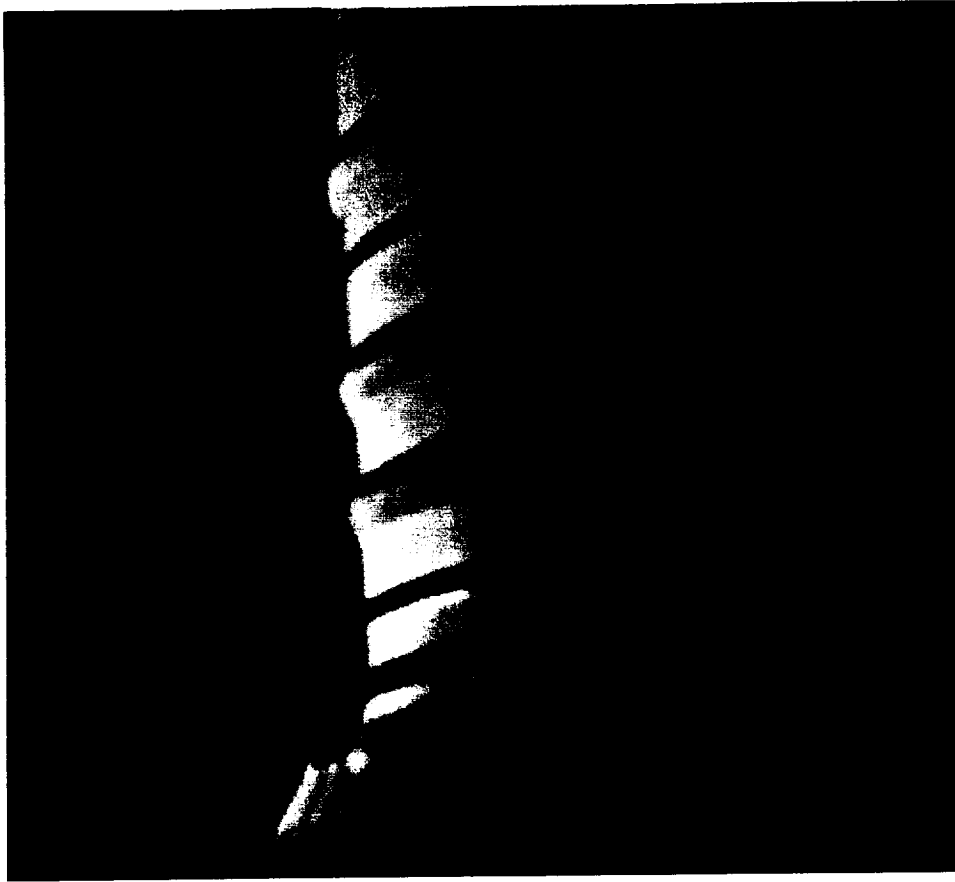


Figure 2.2.1 (B) Flexible Piece of Debris near North Side of LO2 TSM Prior to Liftoff

On camera E2, a large flexible piece of umbilical purge barrier material debris seen on the north side of the LO2 TSM, traveled near the RSRB, and fell aft to the deck of the MLP (11:42:08.891 UTC). See Figure 2.2.1 (B). During liftoff, a piece of ET / Orbiter umbilical purge barrier material was seen to be partially detached before breaking away and falling aft (Camera E31, 11:42:10.794 UTC). The remaining visible umbilical purge barrier material was seen flapping against the Orbiter tiles. The flapping of this material could have resulted in the tile damage found post-landing near the ET / Orbiter umbilicals. After the roll maneuver, another large piece of umbilical purge barrier material was seen falling aft of the vehicle. Umbilical purge barrier material debris has been seen during ascent on previous missions. (Cameras E2, E4, E5, E31, E54, E207, E223)

An unidentified large, thin, square-shaped, dark-colored piece of debris was seen falling along the LSRB near holddown post M-8 prior to SRB ignition. This debris was not seen to contact the launch vehicle. (Camera E14)

## Summary of Significant Events

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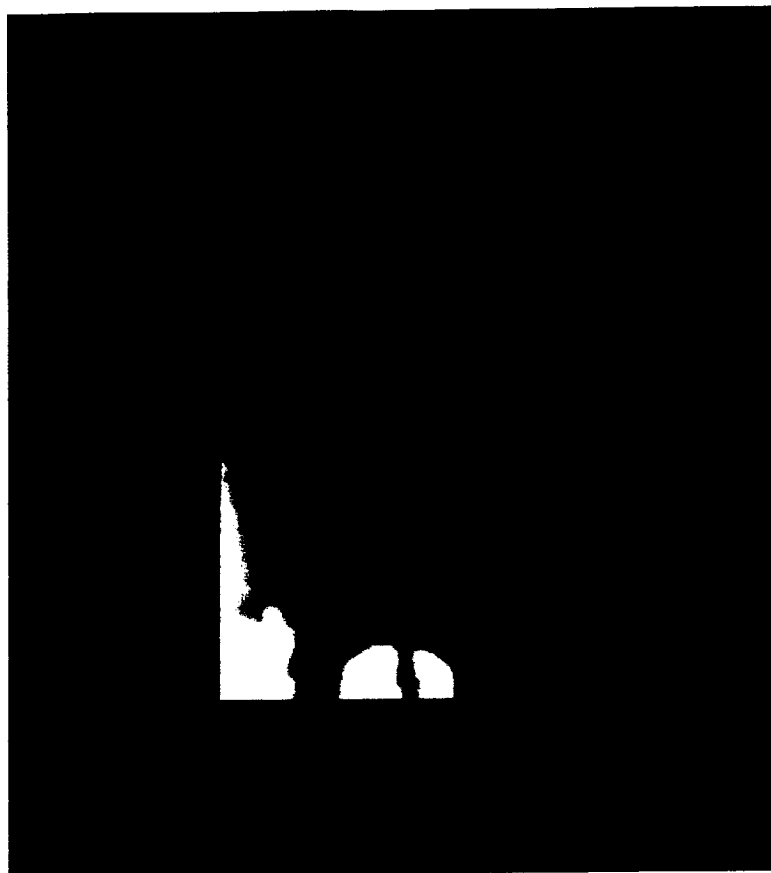


Figure 2.2.1 (C) Debris from SRB Flame Ducts at Liftoff (Camera E222)

Typical of many previous missions, several light-colored pieces of debris were seen traveling from the area of both the right and left SRB flame ducts (probably SRB throat plug material or SRB aft skirt instafoam) in a northerly direction away from the launch vehicle after SRB ignition (11:42:10.838 UTC). A larger, light-colored debris object was seen on the north side of the vehicle at a higher elevation than the other debris. This object was concluded to have been a bird. On camera E1, a piece of probable throat plug material, seen near the left SRB aft skirt, traveled in a +Y direction toward the RSRB and the LO2 TSM. On camera E5, a piece of probable SRB throat plug material was seen moving from near the aft end of the SRB's toward the body flap at liftoff. A single piece of light-colored debris (probable SRB aft skirt instafoam) was seen near the RSRB aft skirt area moving away from the vehicle during liftoff. None of the debris was seen to contact the launch vehicle. (Cameras OTV163, E1, E4, E36, E63, E222, E223, E224)

## **Summary of Significant Events**

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### **2.2.2 Debris During Ascent**

As observed on previous missions, multiple pieces of debris (umbilical ice and RCS paper) were seen near the SSME exhaust plume and falling aft of the launch vehicle during ascent. Also during ascent, several pieces of light-colored debris (probably umbilical ice) were seen along the -Z side of the body flap. Examples are:

Cameras E207, E222, E224 - Multiple pieces of umbilical ice and RCS paper were seen aft of the vehicle after the roll maneuver.

Camera E212 - RCS paper debris was seen near the vertical stabilizer (frames 3940, 4130)

Cameras ET207, E222 - Multiple pieces of umbilical ice debris were seen near the trailing edge of the body flap. (11:42:40.951 UTC)

As on previous missions, light-colored debris was seen exiting the SRB exhaust plumes during ascent. The pieces of debris exiting the SRB exhaust plumes during the majority of the ascent were probably instafoam from the aft end of the SRB's. The more dense appearing debris near the time of tail-off, just prior to SRB separation, were probably SRB slag debris. (Cameras KTV4B, ET207, E207, E212, E223)

### **2.2.3 Mobile Launch Platform (MLP) Events**

Large areas of frost were seen on the External Tank TPS prior to lift off, through tower clear and into the roll maneuver. After the roll maneuver the frost was no longer visible. (Cameras OTV170, KTV4B, E1, E4, E34, E52, E54, E222, E223)

The SSME ignition appeared normal on the high-speed engineering films. However, during SSME start-up the SSME Mach diamonds did not form in the expected sequence (3, 2, 1). Instead, the Mach diamonds formed in a 2, 3, 1 sequence. The times for the Mach diamond formation given in Table 2.2.3 are from film E19. (Cameras E20, E76, OTV151)

<b>SSME</b>	<b>TIME (UTC)</b>
SSME #2	11:42:05.834
SSME #3	11:42:05.889
SSME #1	11:42:06.183

Table 2.2.3 SSME Mach Diamond Formation Times

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims, near the base of the vertical stabilizer, and forward of the trailing edge of the OMS pods during SSME ignition (11:42:04.0 UTC). Orange vapor forward of the SSME rims has been seen on previous mission films and videos. (Cameras OTV171, E1, E4, E5, E17, E18, E19, E20, E36, E63, E76)

## Summary of Significant Events

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Flexing of the SSME #2 Dome Mounted Heat Shield (DMHS) and the base heat shield near SSME #2 was detected during SSME ignition (11:42:05.42 UTC). This movement has been seen on previous mission films. (Camera E18)

As reported by KSC, the stream of sparks from the LH2 south radial outward firing hydrogen ignitor (used to prevent the build up of hydrogen near the SSME's) was not continuous. (Camera E20)

Typical of previous missions, small areas of tile surface coating material erosion were seen on the base heat shield outboard of SSME #3 (11:42:04.7 UTC), on the base heat shield outboard of SSME #2, and on the base of the left RCS stinger (11:42:05.48 UTC) prior to liftoff. (Cameras E17, E18, E19, E20)

What appeared to be a partially detached piece of tape was seen on the LO2 TSM T-0 umbilical feed lines prior to liftoff. (Camera E17)

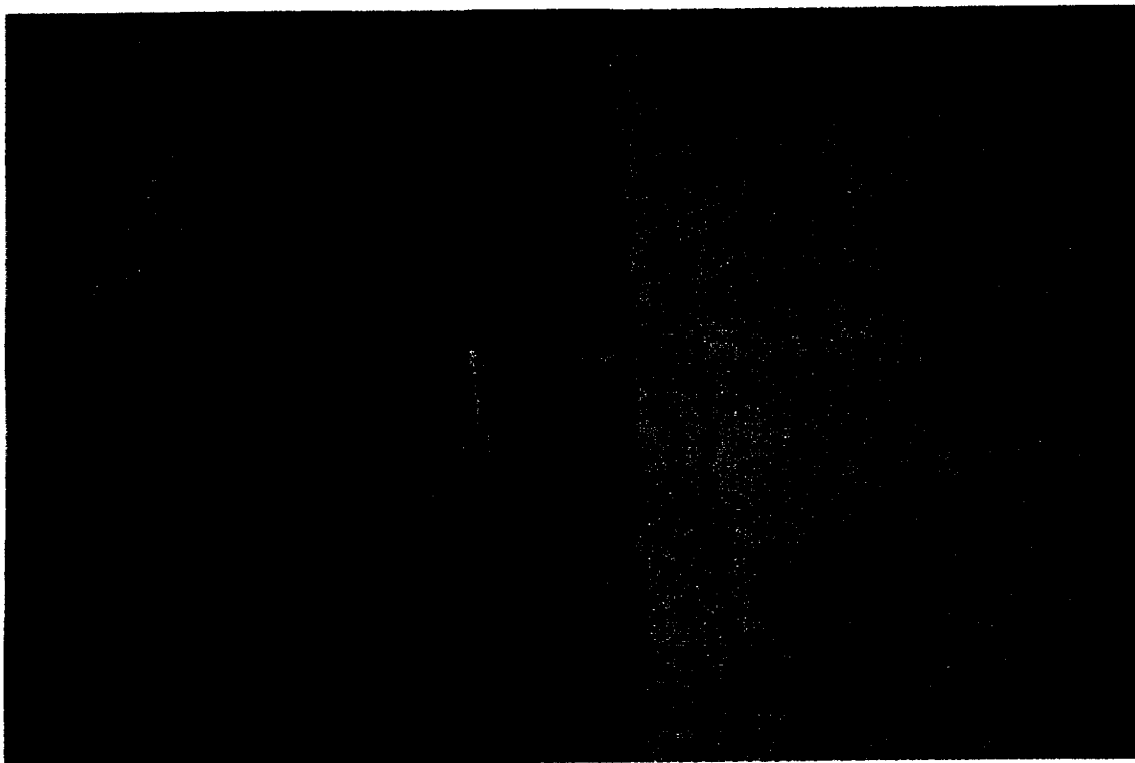


Figure 2.2.3 Barrier Material from LH2 TSM Falling During Liftoff (Camera E18)

A large, clear, piece of flexible closeout / barrier material from the LH2 TSM umbilical compartment was seen falling just after the LH2 TSM umbilical carrier had retracted. (11:42:10.421 UTC). See Figure 2.2.3. (Camera E18, E19)

SRB ignition was at 11:42:09.014 UTC based on the observation of the PIC firing at RSRB holddown post M-1. (Camera E9)

## **Summary of Significant Events**

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Two faint light-colored streaks, typical of previous missions, were seen extending aft of the SSME nozzles prior to liftoff. (Camera E2)

Several large pieces of flexible, water baffle debris were seen near the LSRB flame trench before becoming lost from view in the exhaust cloud during liftoff (11:42:10.846 UTC). At the same time, a dark-colored unidentified piece of debris traveled upward toward the LSRB. The debris did not strike the vehicle. (Camera E4)

A light-colored object reported by KSC to have been a NASA helicopter was seen on the west side of the launch pad after the vehicle cleared the tower (11:42:14.589 UTC). (Camera E52)

An unidentified fluid-like substance (possible water) was seen streaking down the -Y side of the LSRB during liftoff (11:42:12.015 UTC). (Camera E33)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 11:42:10.664 UTC (left purge line) and 11:42:11.046 UTC (right purge line). (Cameras E8, E13)

### **2.2.4 Ascent Events**

Several light-orange-colored flares were noted in the SSME exhaust plume during ascent on the intermediate and long range tracking camera films. Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris is RCS paper. (On STS-26 and STS-101, debris that resulted in very large orange-colored flares was determined to have been tile material.) Examples of flares seen on STS-102 are:

E207    Frames 1671, 1947  
E212    Frame 1761  
E222    11:42:38.035, 11:42:40.425 - 11:42:43.271 UTC  
E223    Frames 3215, 3435, 3620, 3930, 4180, 4640  
ET207  
ET213

Flares in the SSME exhaust plumes have been seen on previous missions films and videos.

The body flap motion seen on STS-102 was less apparent than that seen on STS-97 and STS-98. This may be at least partially due to the soft focus of the long range tracking views (due to atmospheric haze or film processing). Unless requested, no follow-up analysis will be attempted because of soft focus and the relatively small amount of detectable body flap motion. (Camera E207, frames 1671 - 3768)

A partially detached piece of RCS paper was seen on the +Z side of the right RCS stinger during early ascent. (Camera ET207)

A new procedure was implemented by the Shuttle Program to fire the forward RCS thrusters during SRB separation in order to help keep the Orbiter windows free of exhaust particle hazing.

## Summary of Significant Events

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The effects of the firing of the forward RCS were visible in the exhaust plumes near the forward end of the Orbiter. (Camera E207)

Orange vapors from the early OMS-2 assist burn were visible approximately 10.1 seconds after SRB separation (Cameras E207 frame 7825, E212 frame 8028, E223 frame 13060).

### 2.3 Onboard Photography of the External Tank (ET-107)

#### 2.3.1 16mm Umbilical Well Camera Films

The two 16mm umbilical well camera films were disabled preflight because of the investigation into an electric short problem.

#### 2.3.2 35mm Umbilical Well Camera Film

The external tank appeared in excellent condition on the 35mm handheld imagery and the 35 mm umbilical well imagery of the STS-102 External Tank (ET-107). No anomalous conditions on the ET were noted. One special interest observation was noted:

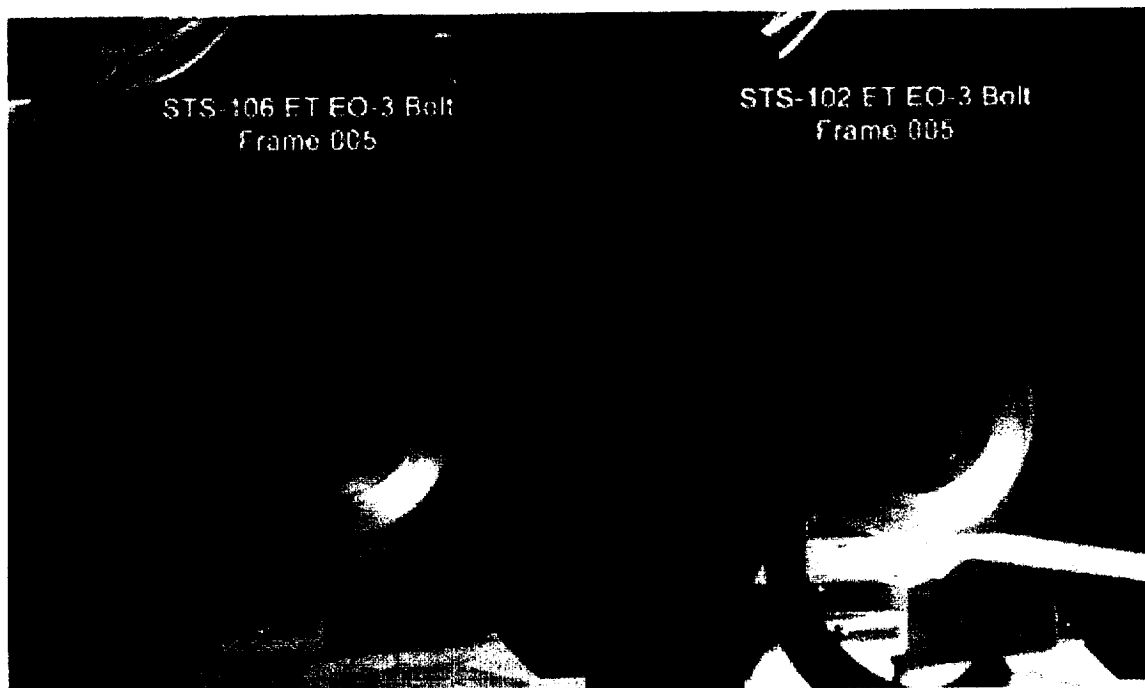


Figure 2.3.2 (A) Comparison of STS-106 and STS-102 ET EO-3 Unretracted Bolts

The separation bolt between the ET and the Orbiter at the aft end of the ET (EO-3 fitting near the liquid oxygen umbilical) was confirmed not to be fully retracted as viewed from the umbilical film. See Figure 2.3.2 (A), image on right. Comparing successive frames, a lateral motion of the bolt was determined to have been present. The EO-3 bolt appeared similar to the protruded EO-3 bolt seen on the STS-106 umbilical well camera film. See Figure 2.3.2 (A), image on left. An attempt to measure the length of the STS-102 unretracted bolt using a parallax method with pairs

## **Summary of Significant Events**

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of images showing the bolt at slightly different angles was unsuccessful because of the bolt motion. An animated movie (gif image) showing the STS-102 bolt motion was created. Also, a previous mission (STS-106) gif image showing a similar protruding bolt with no apparent motion was created for comparison purposes. The STS-102 bolt was clearly "free floating", and not rigid. A rigid bolt is a cause for concern since it could interfere with the proper separation between the ET and the Orbiter. Therefore, this event was not identified as an anomaly. (A Shuttle Program investigation of the STS-106 bolt extension was previously conducted in October, 2001.)

Minor TPS chipping and very small divots (typical of previous missions) were seen on the aft LO2 feedline flanges and on the aft bracket over the press lines. Small, shallow areas of TPS erosion and divoting were visible on the forward flange of the +Y ET/Orbiter thrust strut. Typical ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical were detected. The small "popcorn" divots typically seen on the ET aft dome on previous mission views, were not seen on the visible portions of the ET-107 aft dome.

The face of the LO2 umbilical carrier plate appeared to be in excellent condition (no indication of damaged or missing lightning contact strips was detected).

The red-colored purge seal on the EO-3 ball joint fitting was partially detached but still in the field of view. Detached or missing seals from the EO-3 ball joint fitting were noted on previous mission film screenings.

A small light-colored, irregular-shaped piece of debris was visible near the +Y thrust strut and the aft ET cross beam. The identity of the debris was not confirmed, although the debris appeared to have been a piece of frozen hydrogen.

The +Z LH2 tank TPS was in shadow and too dark for analysis. However, the visible portions of the +Y LH2 tank TPS appeared to be in excellent condition.

## Summary of Significant Events

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Figure 2.3.2 (B) 35mm Umbilical Well Camera View of ET Intertank

An approximately nine inch long white-colored mark (possible TPS ablation) was visible on the forward end of the PAL ramp (just aft of the forward LO2 feedline bellows). See Figure 2.3.2 (B).

The visible portion of the +Z/+Y ET Thrust Panel appeared in excellent condition and no divots were seen on the TPS between the +Y forward SRB attach and the LO2 feedline. The separation burn scar from the RSRB on the +Y ET TPS appeared normal. As expected, the left (-Y) SRB thrust panel was not imaged on this film.

The LH2 tank-to-intertank flange closeout in the -Y direction from the LO2 feedline and the bipod jack pad close outs were obscured from view by shadow. No divots were seen on the visible, non-shadowed, intertank rib heads forward of the bipod. No divots were seen on the LH2 tank-to-intertank close-out flange in the +Y direction from the LO2 feedline.



## Summary of Significant Events

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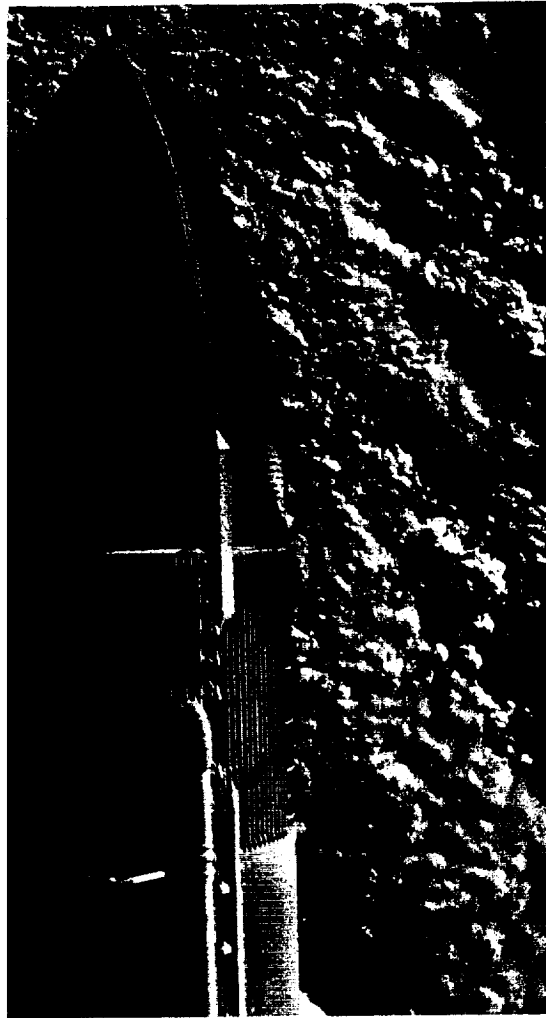


Figure 3.2.3 (C) 35mm Umbilical Well Camera View of Forward ET

The LO2 tank / Ojive TPS appeared to be in excellent condition. The nose of the ET appeared free of damage and the nose cap appeared in good condition. The aero friction and aero heating marks seen on the TPS just aft of the nose cone appeared normal and were less than that typically seen on previous missions.

Notes: The 35mm umbilical well camera film (roll 379) was recorded from the Orbiter LO2 umbilical well. Fifty-nine excellent quality frames imaging the ET were acquired. The +X translation maneuver was performed on STS-102 to facilitate the imaging of the ET with the umbilical well camera.

### 2.3.3 ET Handheld Photography

Crew handheld views of the nose, the aft dome, both limbs (+/- Y sides), and the far side (-Z) of the ET were obtained. The ET was fully illuminated with very little shadowing. The distance of the ET from the Orbiter was calculated to be approximately 3 km on the first photographic frame

## Summary of Significant Events

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acquired. The minimum resolvable object size on the handheld film at 3 km was estimated to be approximately nine inches.

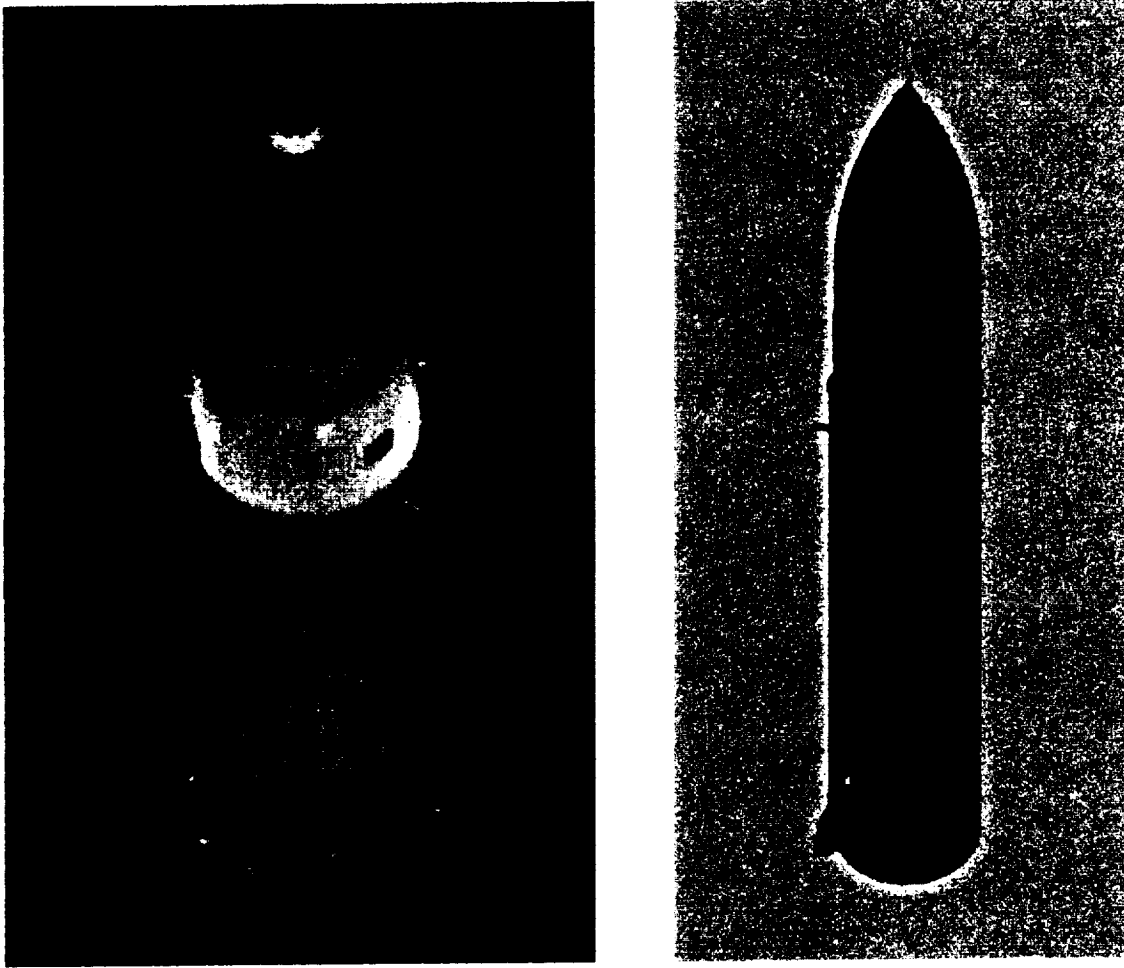


Figure 2.3.3 Crew Handheld Images of the External Tank

The normal SRB separation burn scars and aero-heating marks were noted on the intertank and nose TPS of the ET. The LO2 tank / Ojive TPS appeared to be in good condition. However, there were several light-tone marks on the -Z side of the nose that appeared to be ablated TPS. See Figure 2.3.3, Crew Handheld Images of the External Tank (arrow).

The +Y ET thrust panel appeared in satisfactory condition. No significant divoting of the thrust panel TPS was confirmed from the handheld imagery. The -Y thrust panel was imaged at an oblique angle due to the attitude of the ET relative to the Orbiter when the pictures were taken. No divots were seen on the visible portion of the -Y thrust panel.

No divots or unusual marks were seen on the LH2 tank TPS and the ET aft dome.

Notes: Thirty-six excellent quality handheld pictures of the External Tank were acquired using the handheld 35mm Nikon F5 camera with a 400mm lens (roll 311). Timing data is present on

## Summary of Significant Events

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the film with the first picture being taken at 19:01 (minutes : seconds) MET. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld photography.

### 2.3.4 ET Handheld Video

The handheld video was good quality. The video of the ET was acquired using the new PD-100 camcorder. The tumble rate of the ET was measured to be approximately 12 degrees per second from the video. This rate was greater than the ET tumble rate measured on STS-101 and STS-106 and was probably due to the later MET when the ET was imaged. No venting was seen from the ET intertank gaseous hydrogen vent on the STS-102 video.

### 2.4 Landing Events Timing

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 2.4.

STS-102 Landing and Drag Chute Event Times from Video:

Event Description	Time (UTC)	Camera
Main gear door opening	~080:07:31:19.821	NASA Select Video
Left main gear tire touchdown	~080:07:31:41.286	SLF North
Right main gear tire touchdown	~080:07:31:41.676	NASA Select Video
Nose gear tire touchdown	~080:07:31:51.953	NASA Select Video
Drag chute initiation	~080:07:31:54.656	NASA Select Video
Pilot chute at full inflation	Not Observed	NA
Bag release	Not Observed	NA
Drag chute inflation in reefed configuration	Not Observed	NA
Drag chute inflation in disreefed configuration	~080:07:32:01.436	KTV5L
Drag chute release	080:07:32:30.845	KTV11
Wheel Stop	~080:07:33:01.008	KTV11

Note: ~ Denotes that the time shown is approximate.

Table 2.4 Landing Event Times

## Summary of Significant Events

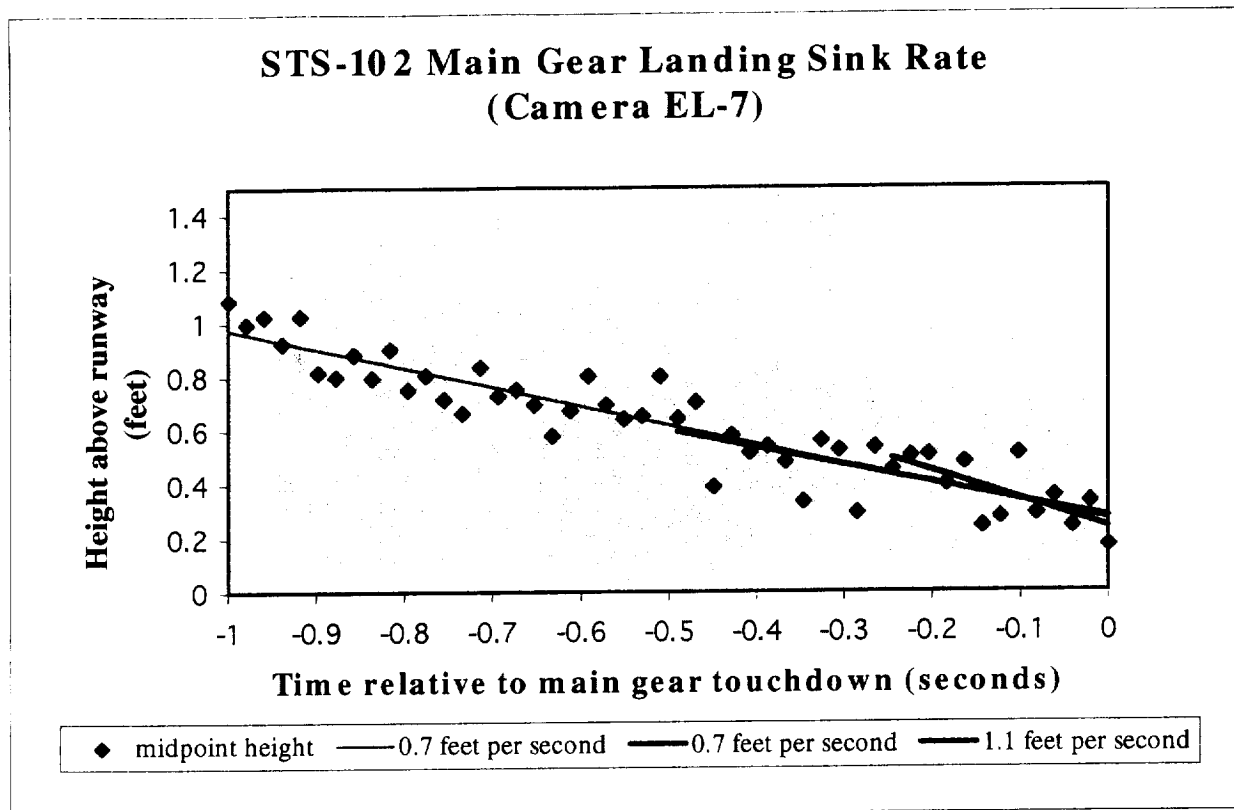


Figure 2.5 Main Gear Midpoint Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet / second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-102 vehicle was reported to be 218,304 lbs.

## **Summary of Significant Events**

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### **2.6 Other**

#### **2.6.1 Normal Events**

Normal events observed included:

- elevon motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and / after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff
- debris in the exhaust cloud (including water baffle material) after liftoff
- charring of the ET aft dome
- ET aft dome outgassing
- roll maneuver
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

#### **2.6.2 Normal Pad Events**

Normal pad events observed included:

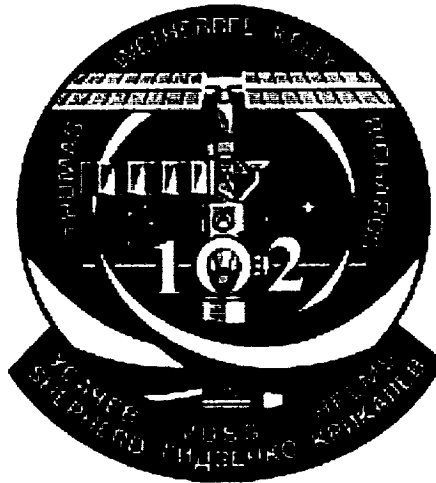
- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical disconnect and retraction
- LH2 and LO2 TSM door closures

## **APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY**



# Space Shuttle Mission STS-102

## Engineering Photographic Analysis Summary Report Marshall Space Flight Center



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## Engineering Photographic Analysis Report for STS-102

Launch of the one-hundred-third Space Shuttle mission, STS-102, the twenty-ninth flight of the Orbiter Discovery (OV-103), occurred March 8, 2001 at approximately 5:42 AM CST, from launch complex 39B, Kennedy Space Center (KSC), Florida. Launch time was reported as 01:067:11:42:09.004 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.



### STS-102 Photographic Analysis Summary:

No significant out-of-family conditions or anomalous events were observed on launch film or video products covering Space Shuttle Mission STS-102.

Two unusual debris items were noted on this flight: A circular debris object near HDP M1, and a clear flexible plastic closeout/barrier sheet from the LH2 TSM Umbilical compartment.

The EO-3 Interface Bolt was observed to be protruding from the EO-3 Interface Ball Joint bore on this mission.

### Photographic Analysis Website:

Further information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

<http://photo4.msfc.nasa.gov/STS/sts102/sts102.html>

Information available on the MSFC Engineering Photographic Analysis website includes:

- Photographic Acquisition Disposition Document (PADD),
- Individual camera status and assessments,
- Annotated images of notable observations,
- Movies of select events, and
- Photographic Analysis Mission Summary Report ( PDF format).

### Photographic Coverage:

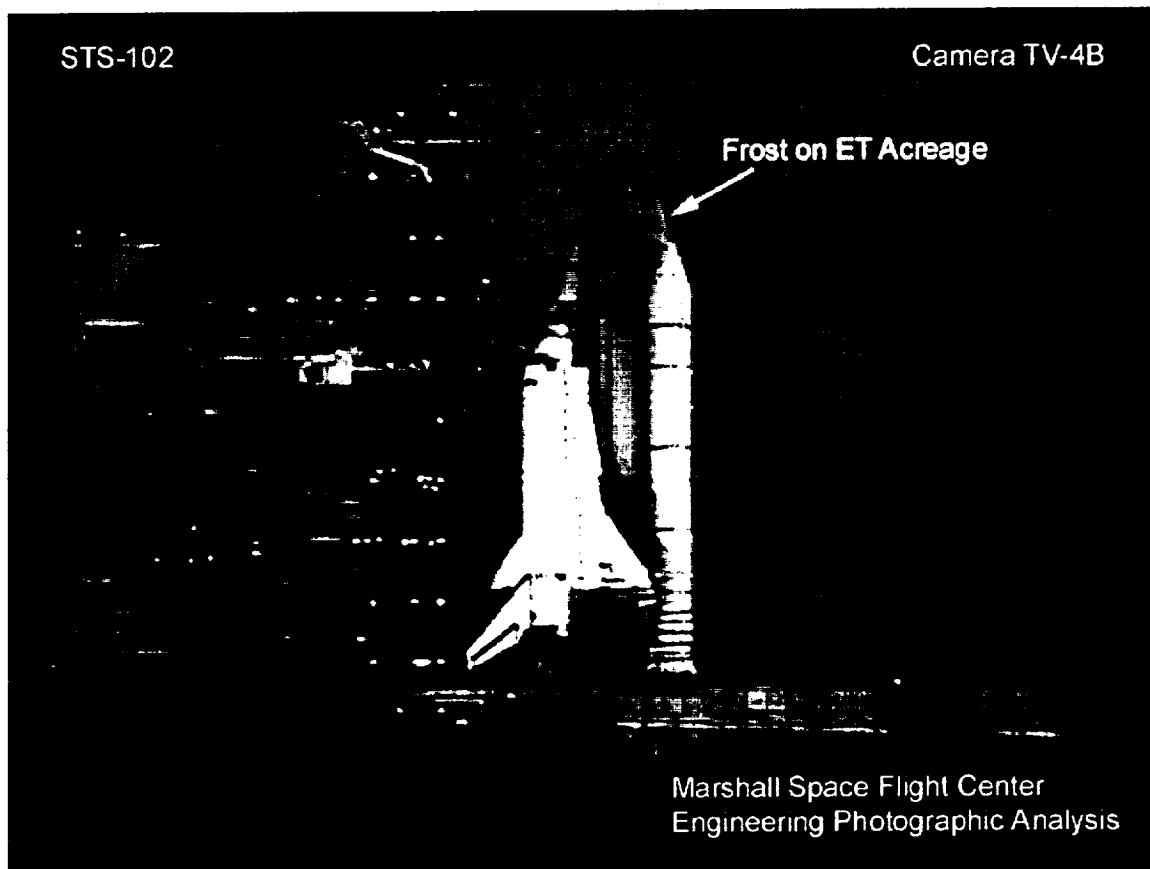
Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Sixty-five engineering photographic products consisting of launch video, ground-based engineering films and onboard film were received and reviewed at MSFC. Camera coverage received at MSFC for STS-102 is illustrated in the following table.

## Observations:

### *Video Camera TV-4B: Frost on ET Acreage*

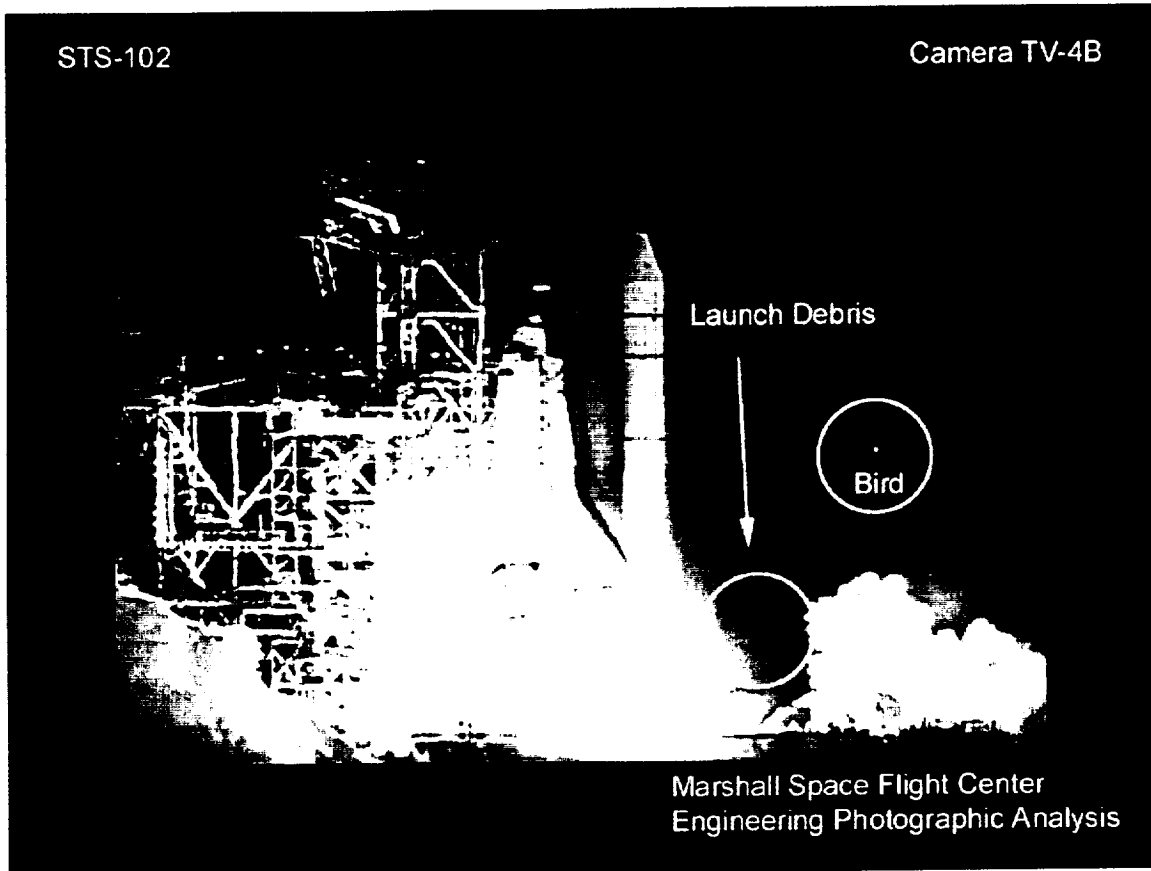
A large area of the External Tank was coated with frost prior to liftoff. Frost was not observed on later film/video and assumed to have sublimed or evaporated quickly during vehicle ascent.



**Figure 1. Frost on ET Acreage**

***Video Camera TV-4B: Pad Debris at SRB Ignition***

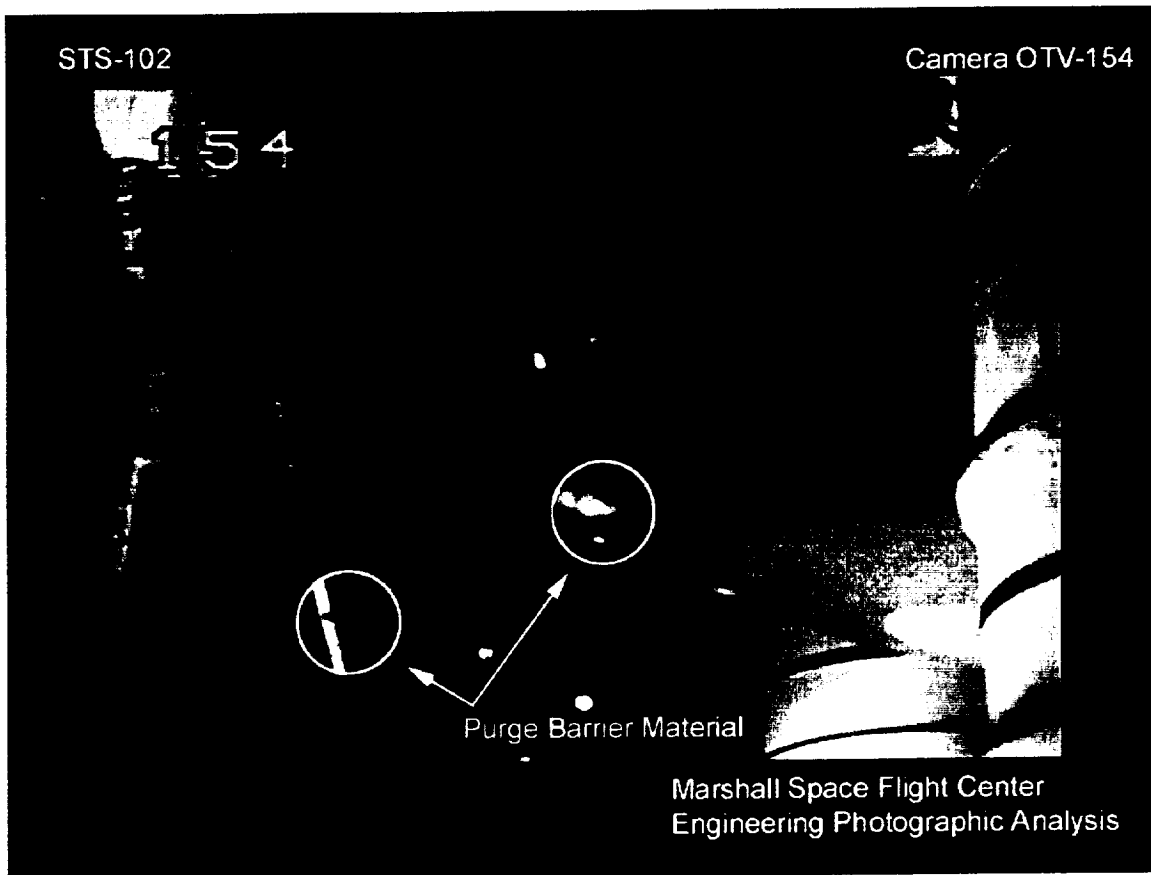
Several typical launch pad debris items were observed at SRB ignition. A bird was also observed near the launch site.



**Figure 2. Pad Debris at SRB Ignition**

### ***Video Camera OTV-154: Purge Barrier Material Debris***

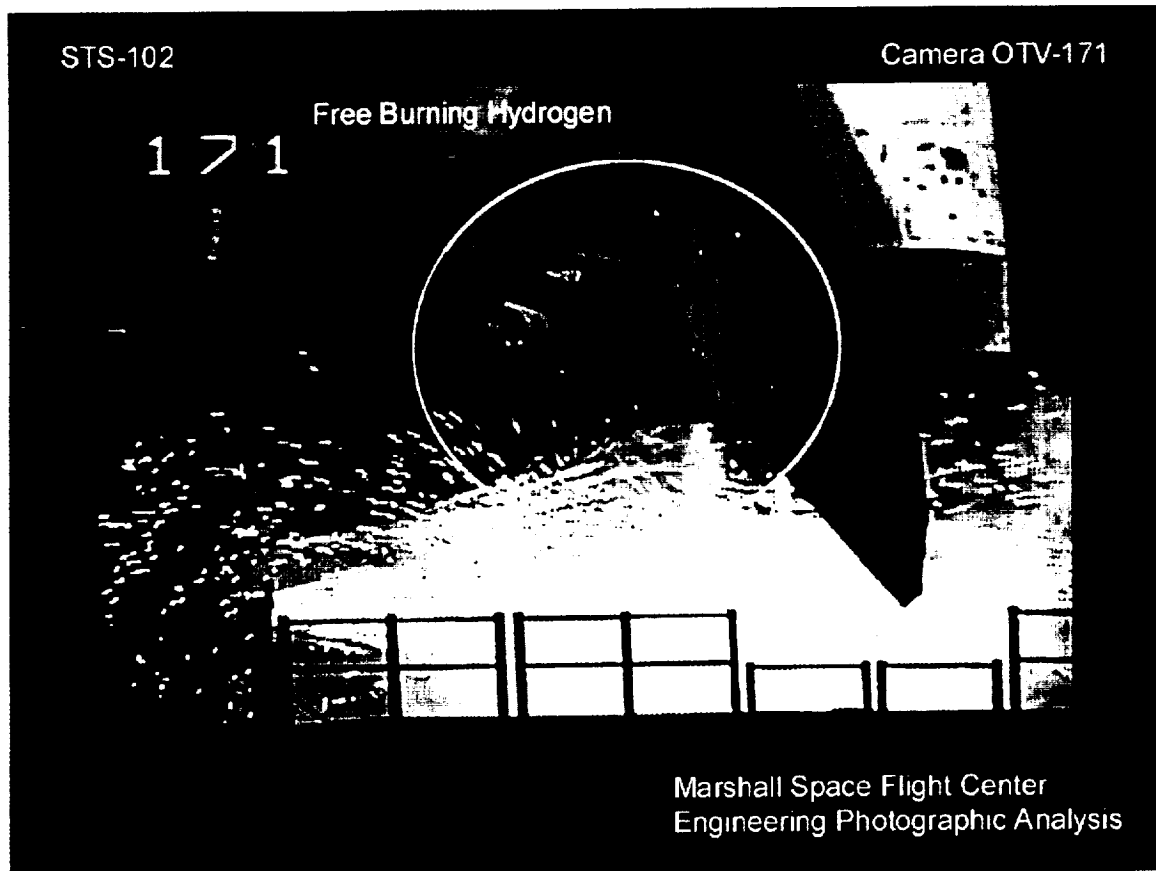
Several pieces of purge barrier material debris were observed falling through the field of view. These appeared to come from both the LOX and LH2 17-inch disconnects.



**Figure 3. Purge Barrier Material Debris**

***Video Camera OTV-171: Free Burning Hydrogen at SSME Ignition***

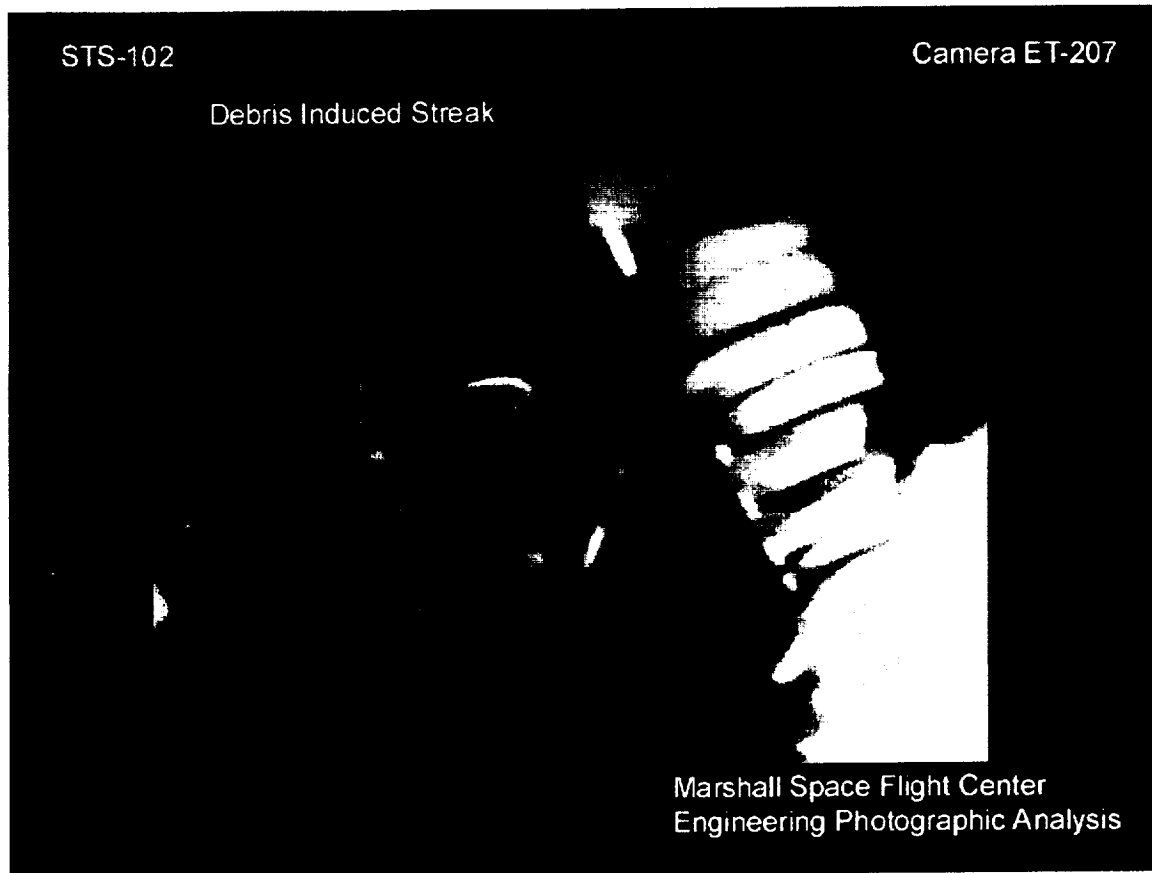
Free burning Hydrogen was observed at SSME ignition, extending forward of the -Y (left) OMS Pod rim. This particular phenomenon is a typical occurrence during SSME ignition and appears to be within normal limits.



**Figure 4. Free Burning Hydrogen at SSME Ignition**

***Video Camera ET-207: Streak in SSME Plumes***

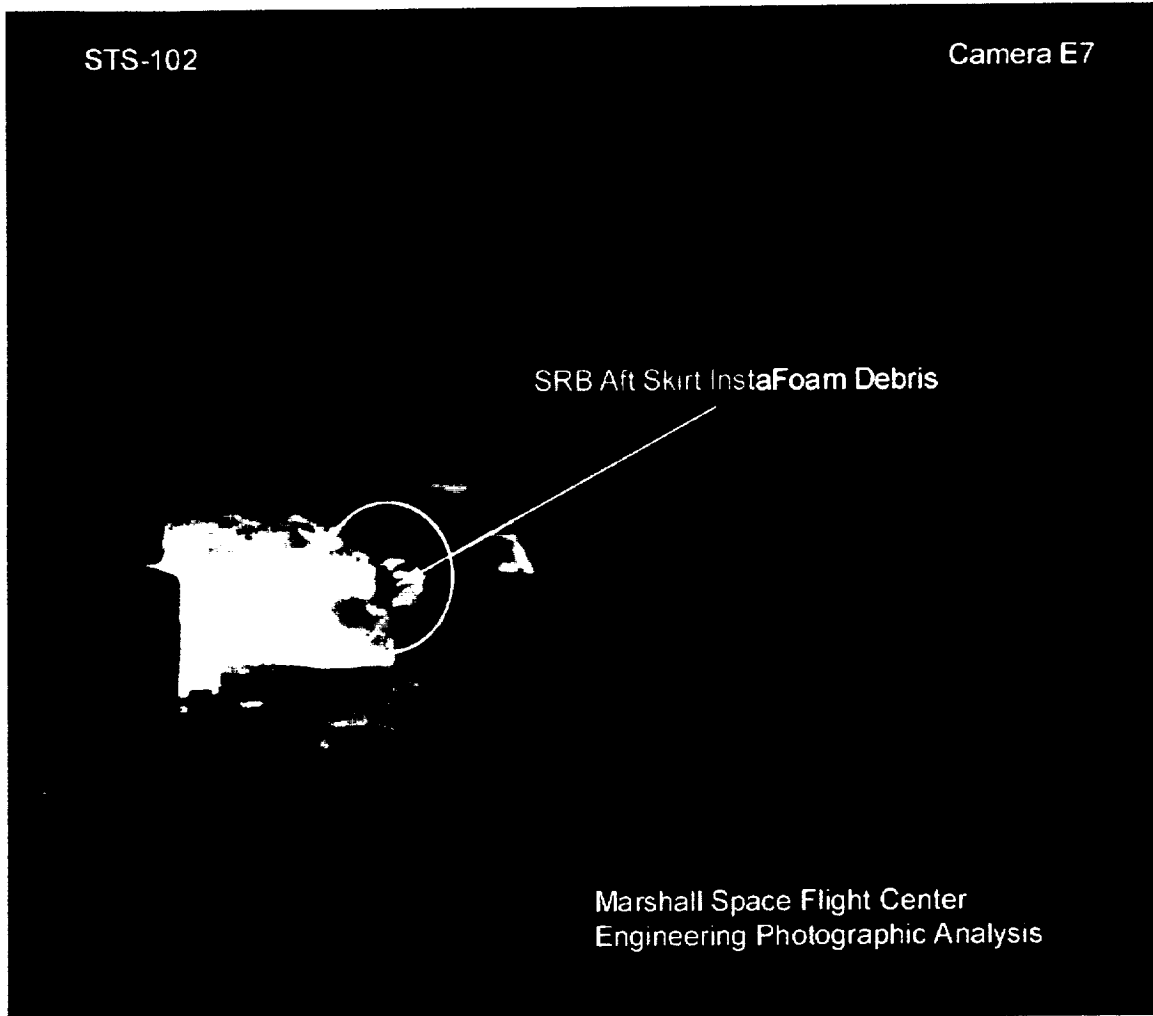
Several debris induced streaks in the SSME plumes were noted during ascent. Figure 5 illustrates one such event.



**Figure 5. Debris Induced Streak in SSME Plumes**

***Film Camera E7: InstaFoam Debris***

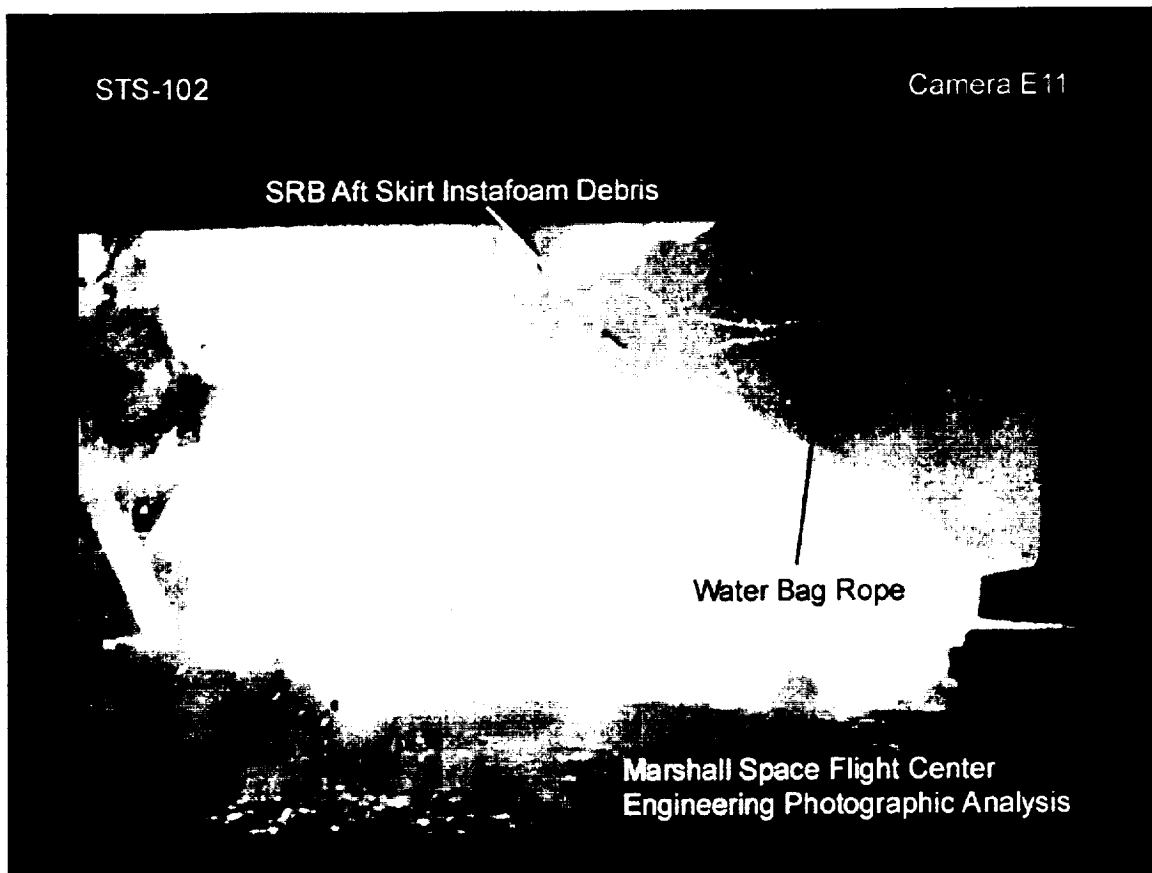
A notable chunk of Aft Skirt Instafoam was observed to break free after impact with the Shoe of Holddown Post M4.



**Figure 6. Instafoam Debris at Holddown Post M4**

***Film Camera E11: Instafoam Debris***

Another notable chunk of Aft Skirt Instafoam was observed free near Holddown Post M7.

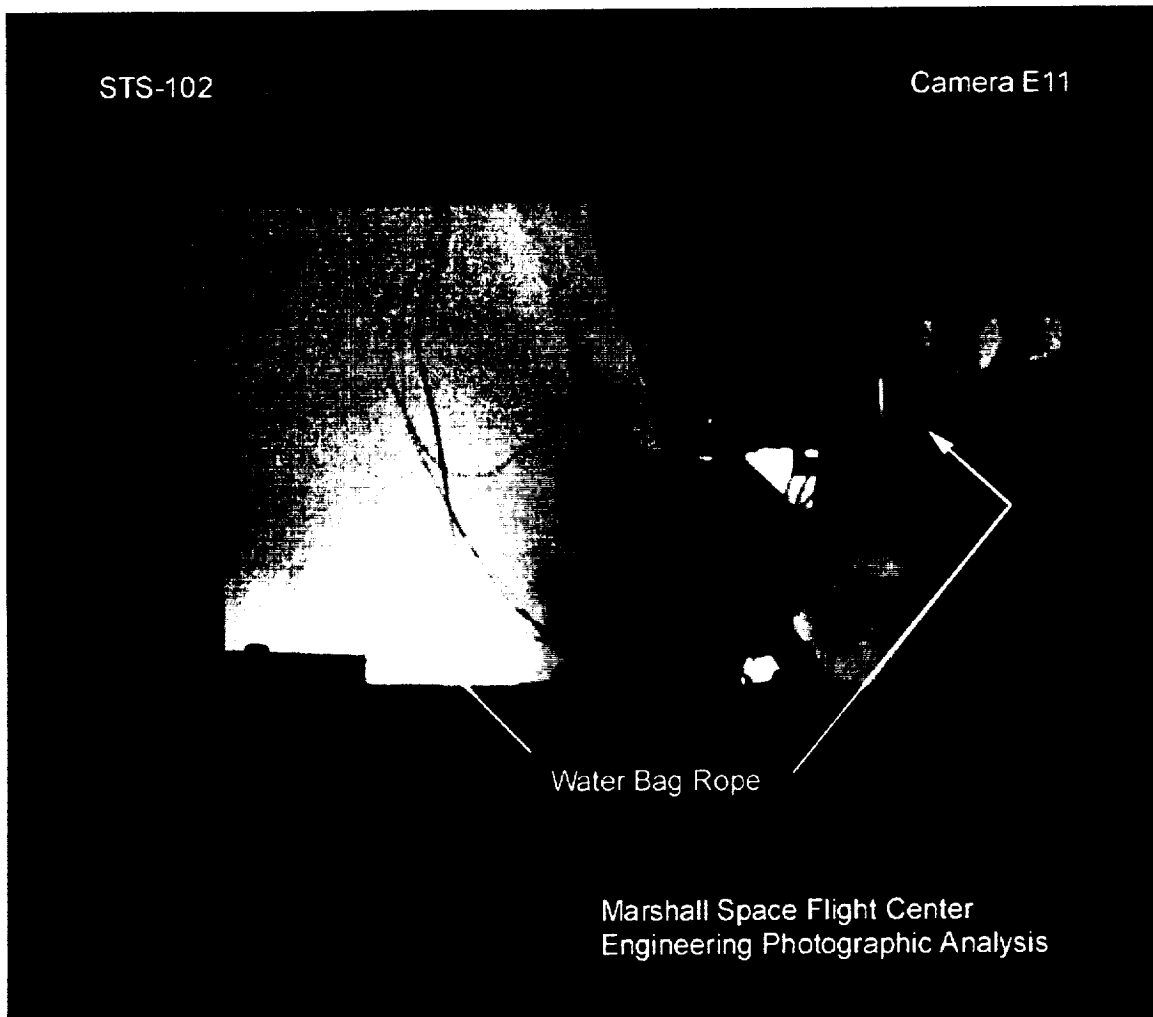


**Figure 7. Instafoam Debris at Holddown Post M7**



***Film Camera E11: Tangle of Water Bag Ropes***

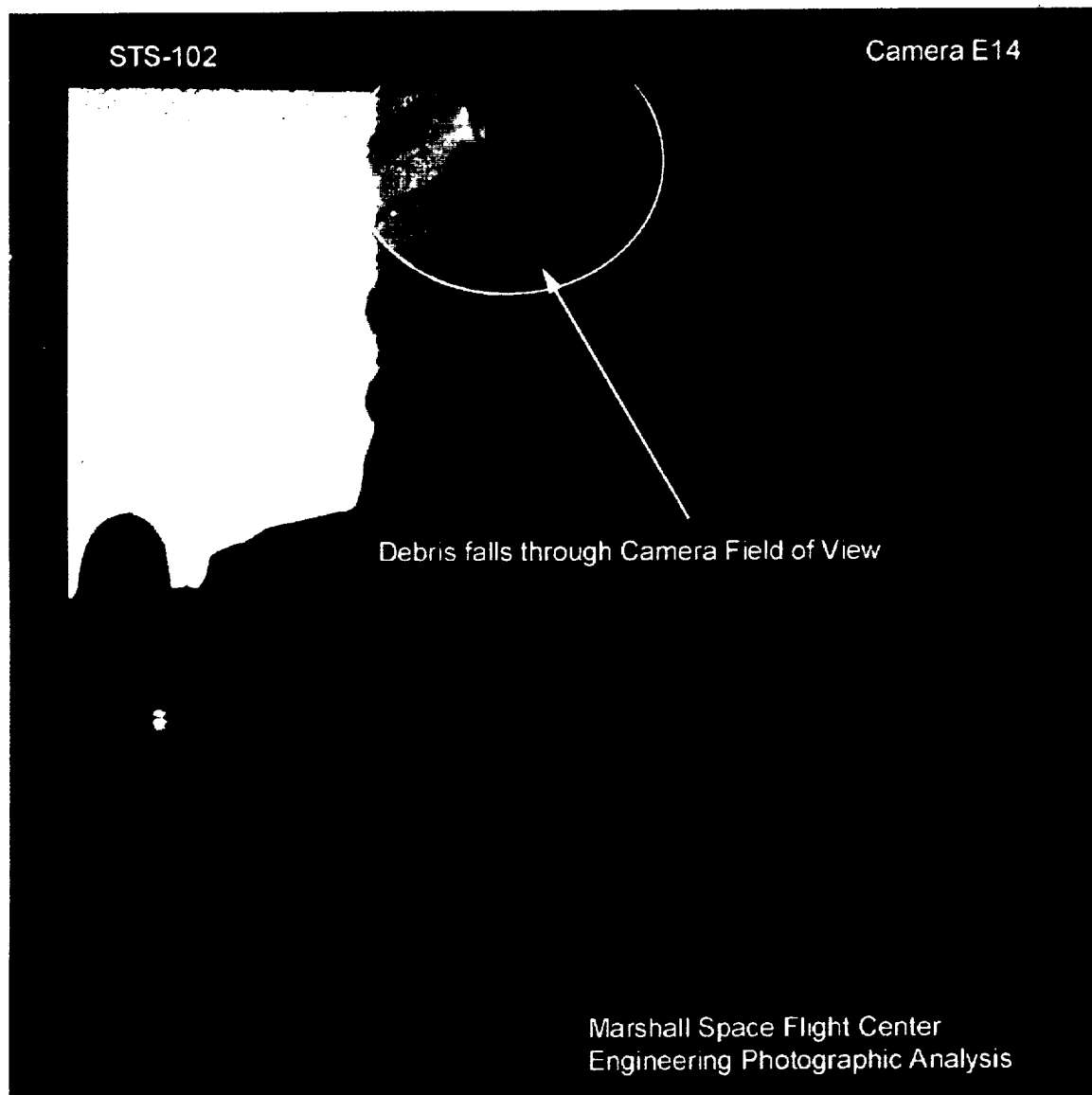
Several Water Bag Ropes were ejected from the SRB flame trench in the vicinity of Holddown Post M8. Water bag ropes have been observed on many previous missions. However, the number of these ropes was greater than usual.



**Figure 8. Tangle of Water Bag Ropes at Holddown Post M8**

***Film Camera E14: Launch Pad Debris***

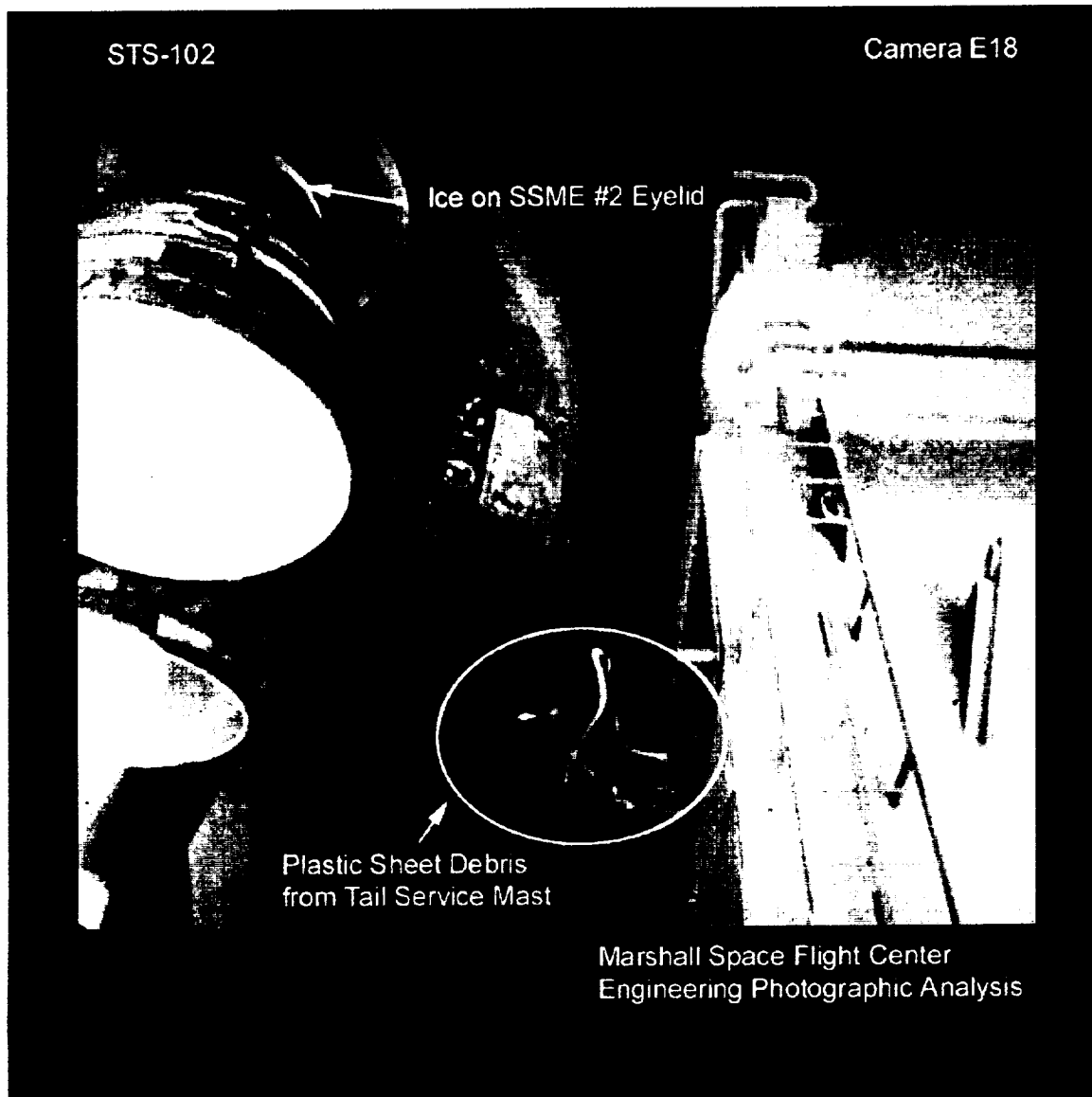
An unidentified, dark, somewhat notched debris item was observed near Holddown Post M7, falling through the field of view, just after SRB ignition. Since the object is out of focus, it is assumed to be near the camera.



**Figure 9. Launch Pad Debris Near Holddown Post M7**

***Film Camera E18: Debris from Tail Service Mast***

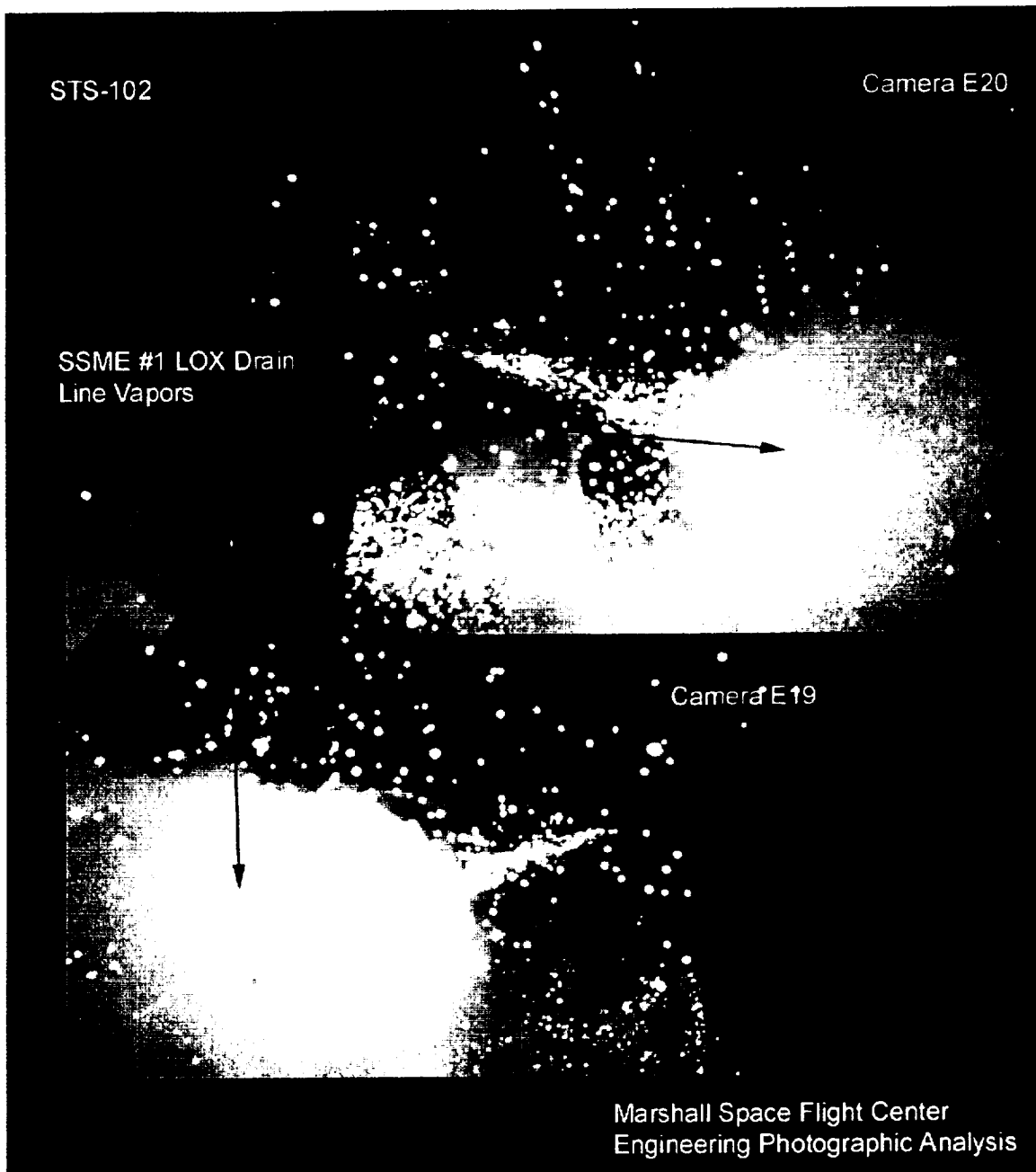
A sheet of plastic debris, identified as closeout/barrier material from the LH2 TSM Umbilical compartment, fell through the field of view, just after retraction of the LH2 T0 umbilical carrier. Also visible is ice around the SSME#2 eyelid.



**Figure 10. Debris from the Tail Service Mast**

***Film Cameras E19 and E20: Streak in SSME Plumes***

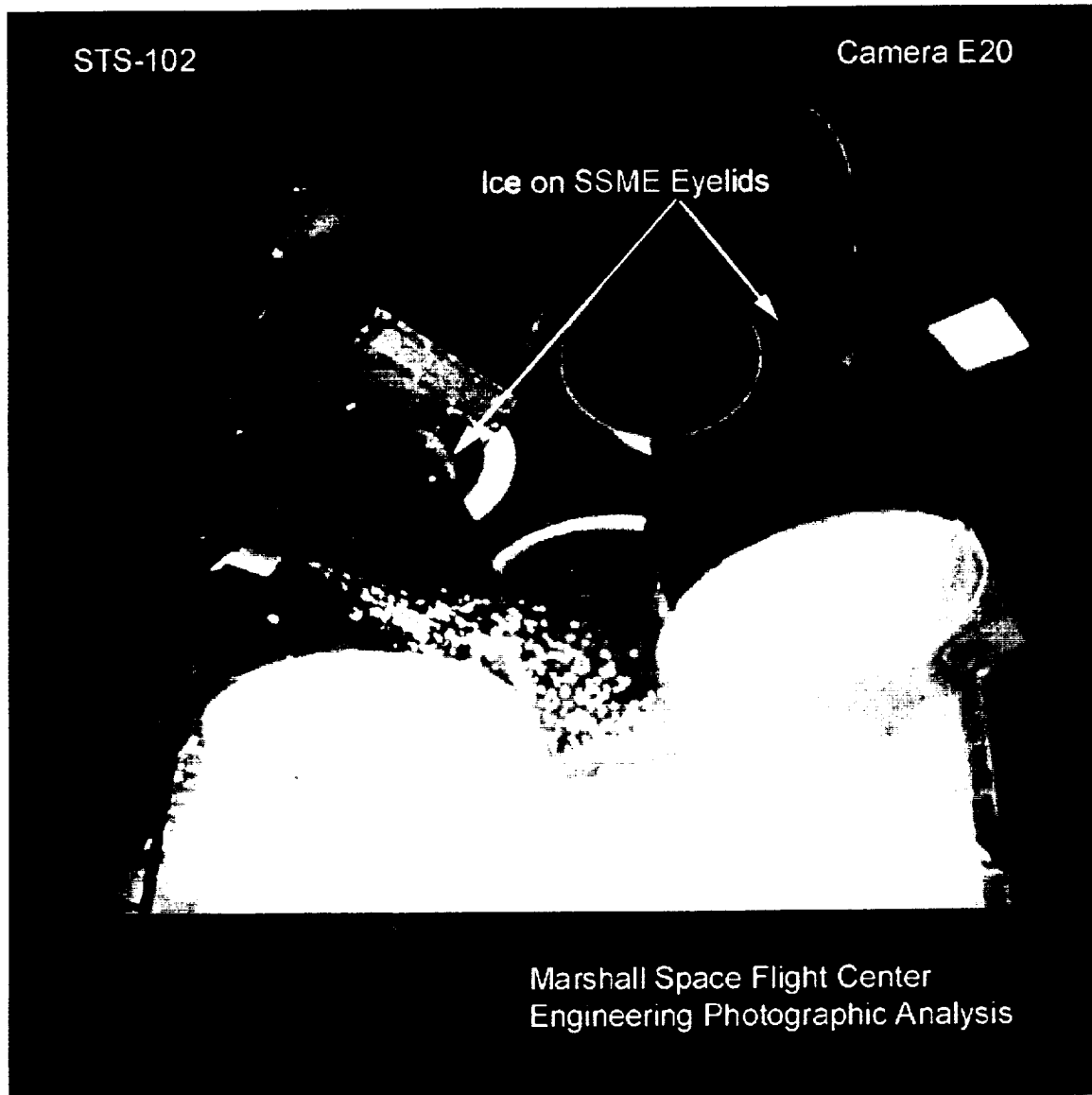
An unusual cloud , presumably LOX vapor originating from an SSME#1 LOX vent drain line, was observed on this mission. Possibly a shift in the winds from the SSME flame exhaust hole toward SSME#1 caused this accumulation of vapors.



**Figure 11. SSME#1 LOX Vent Cloud**

***Film Camera E20: Ice On SSME Eyelids***

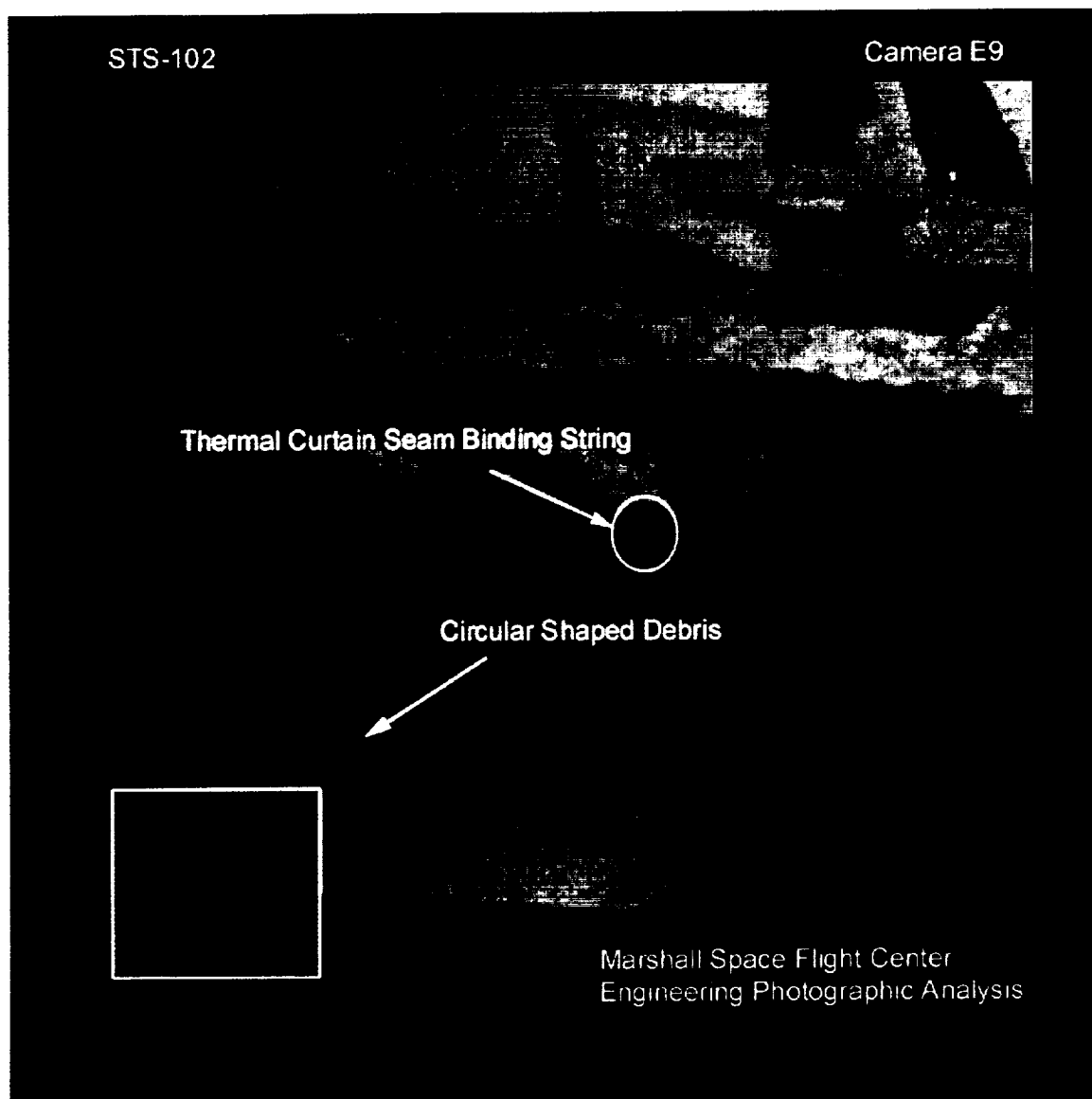
Ice or frost was observed on both SSME#2 and SSME#1 eyelids. It is uncommon to see the ice or frost on SSME#1 eyelid.



**Figure 12. Ice on SSME Eyelids**

***Film Camera E9: Circular Shaped Debris***

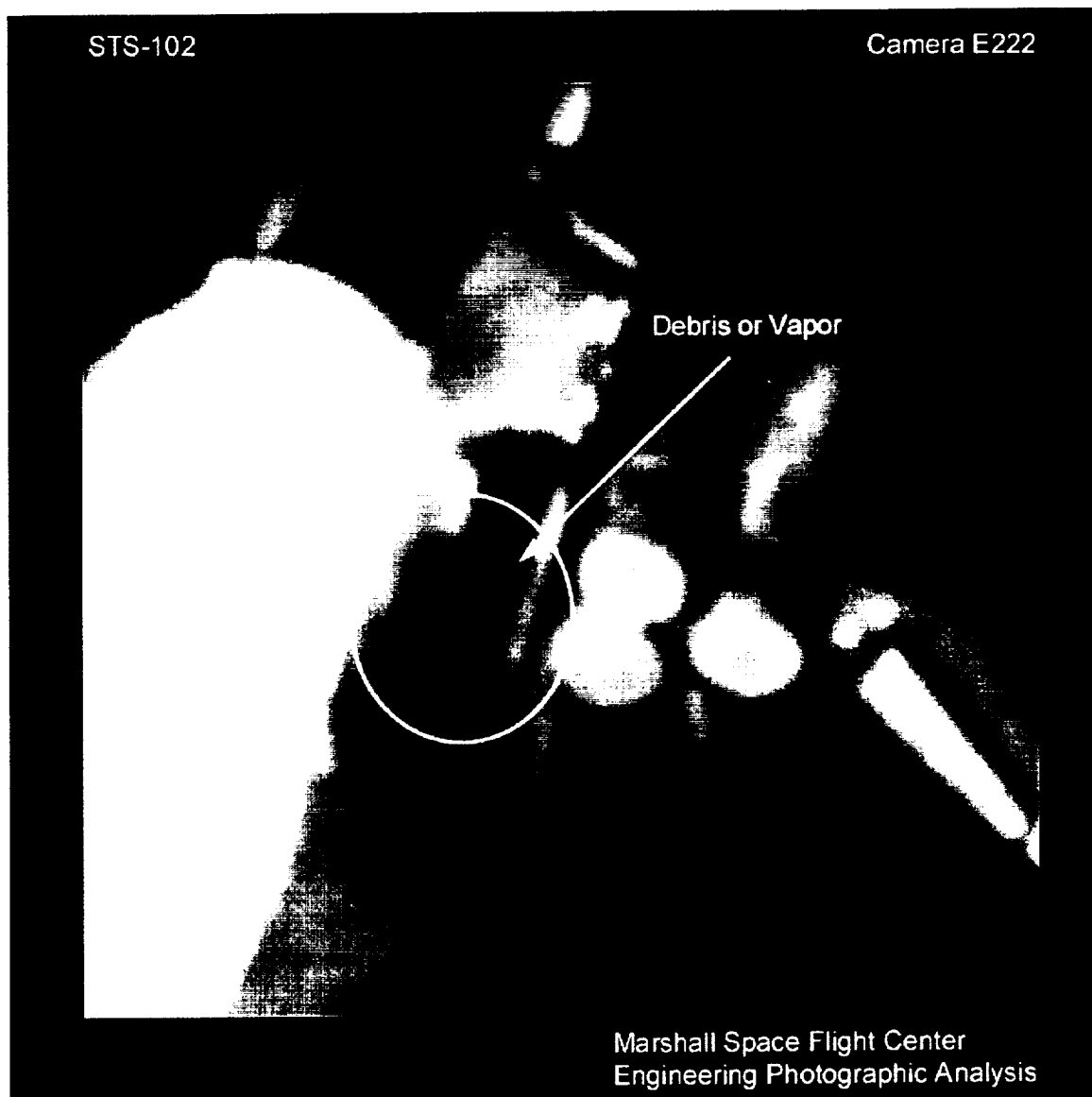
A circular shaped debris object was noted just after liftoff. Also, ends of threads used to bind Thermal Curtain Seams were noted.



**Figure 13. Circular Shaped Debris Object near Holddown Post M1**

***Film Camera E222: Debris Streak***

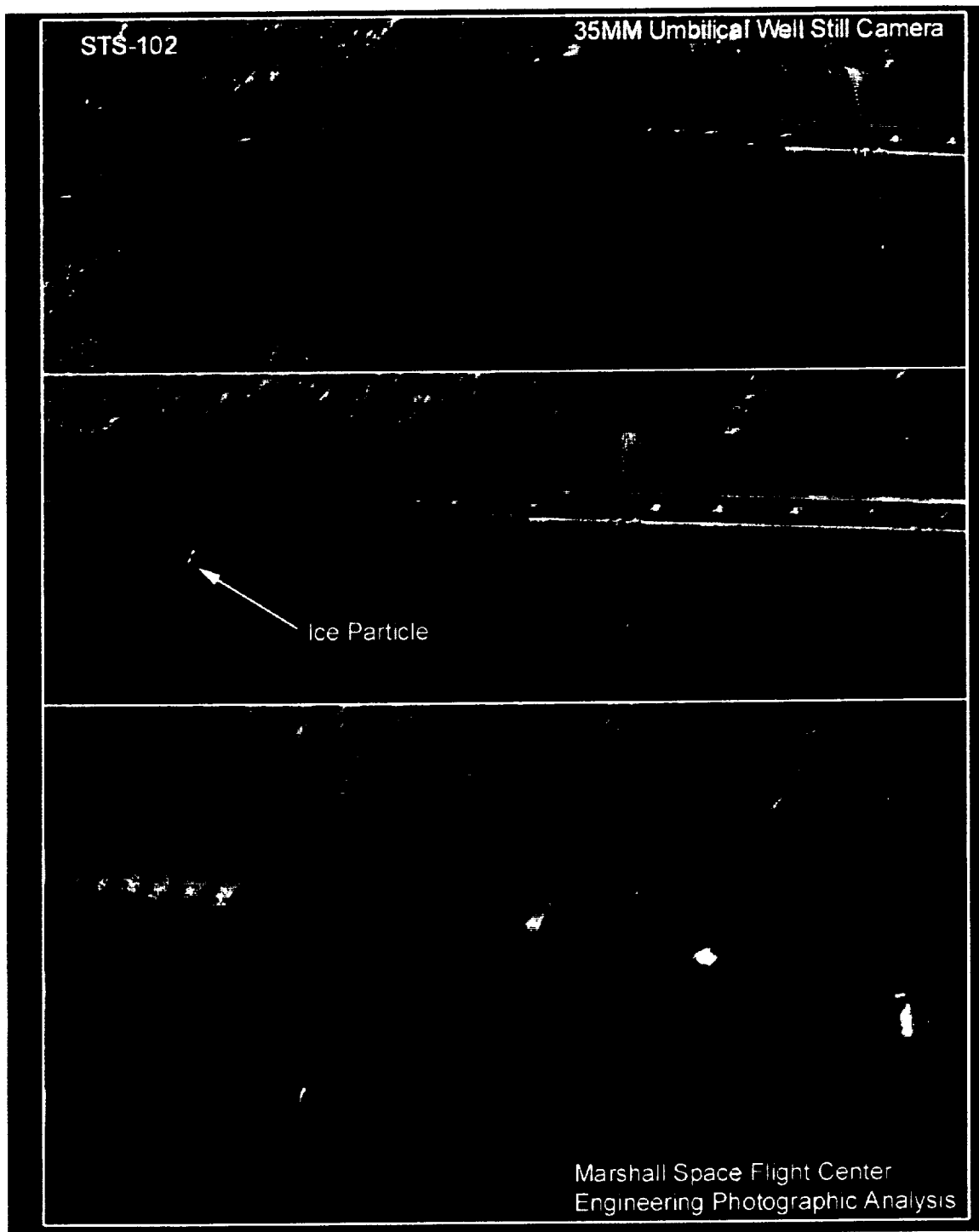
A possible debris or vapor streak was observed apparently between the Orbiter Body Flap and the SRBs.



**Figure 14. Debris or Vapor Streak**

***Umbilical Well 35mm Still Film Camera: External Tank TPS***

TPS on External Tank appeared to be in very good condition. Several small ice particles were noted in the field of view between the Orbiter and the ET. Popcorning in the vicinity of the ET aft dome appeared minimal. The protruding EO-3 interface Joint Bolt may be seen in the bottom image of Figure 16.

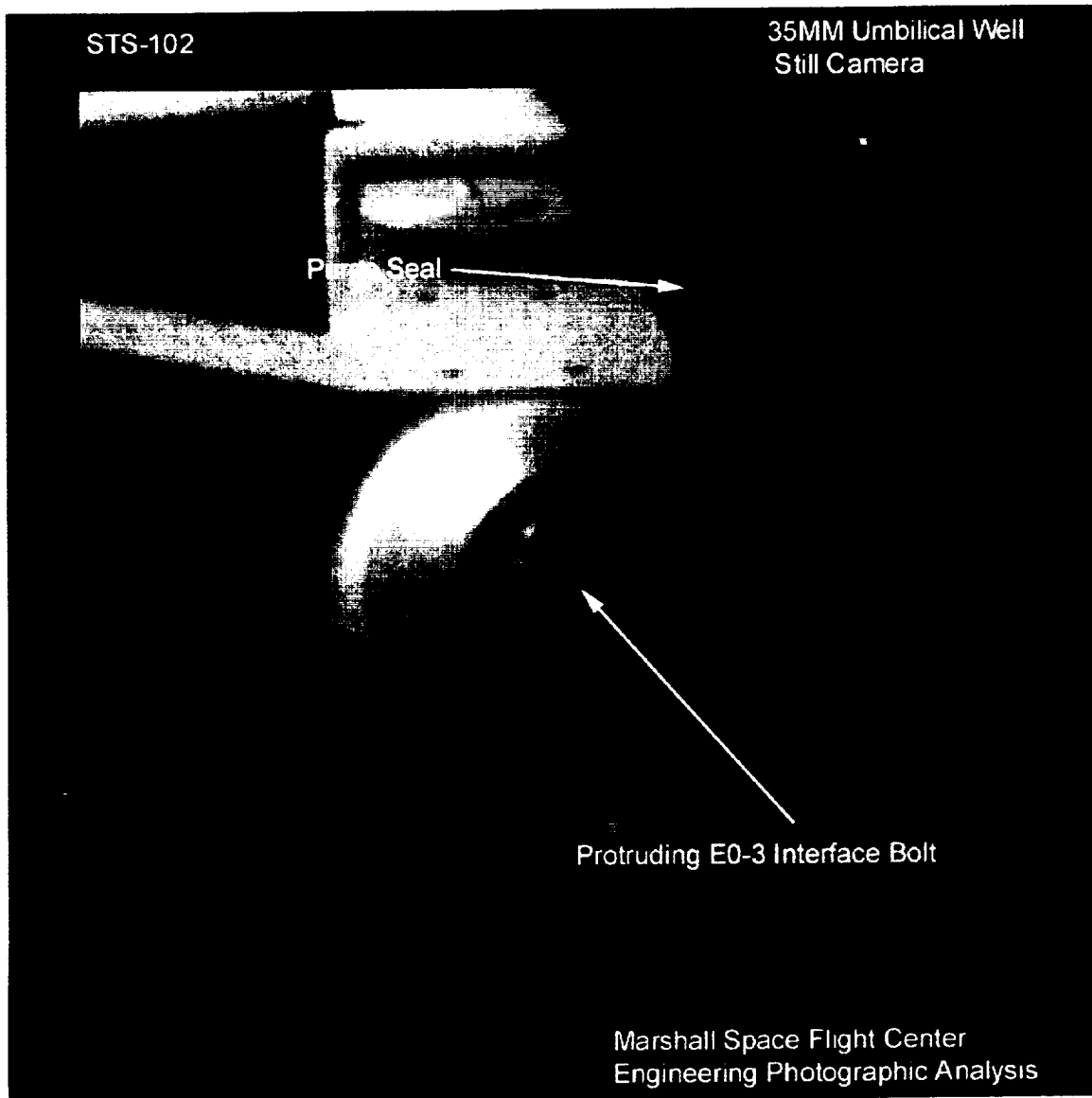


**Figure 15. External Tank TPS**



***Umbilical Well 35mm Still Film Camera: Protruding EO-3 Interface Bolt***

The EO-3 Interface Bolt was noted to be protruding from the bore of the EO-3 Interface Ball Joint. Also, the tethered red-colored purge seal was observed near the joint.

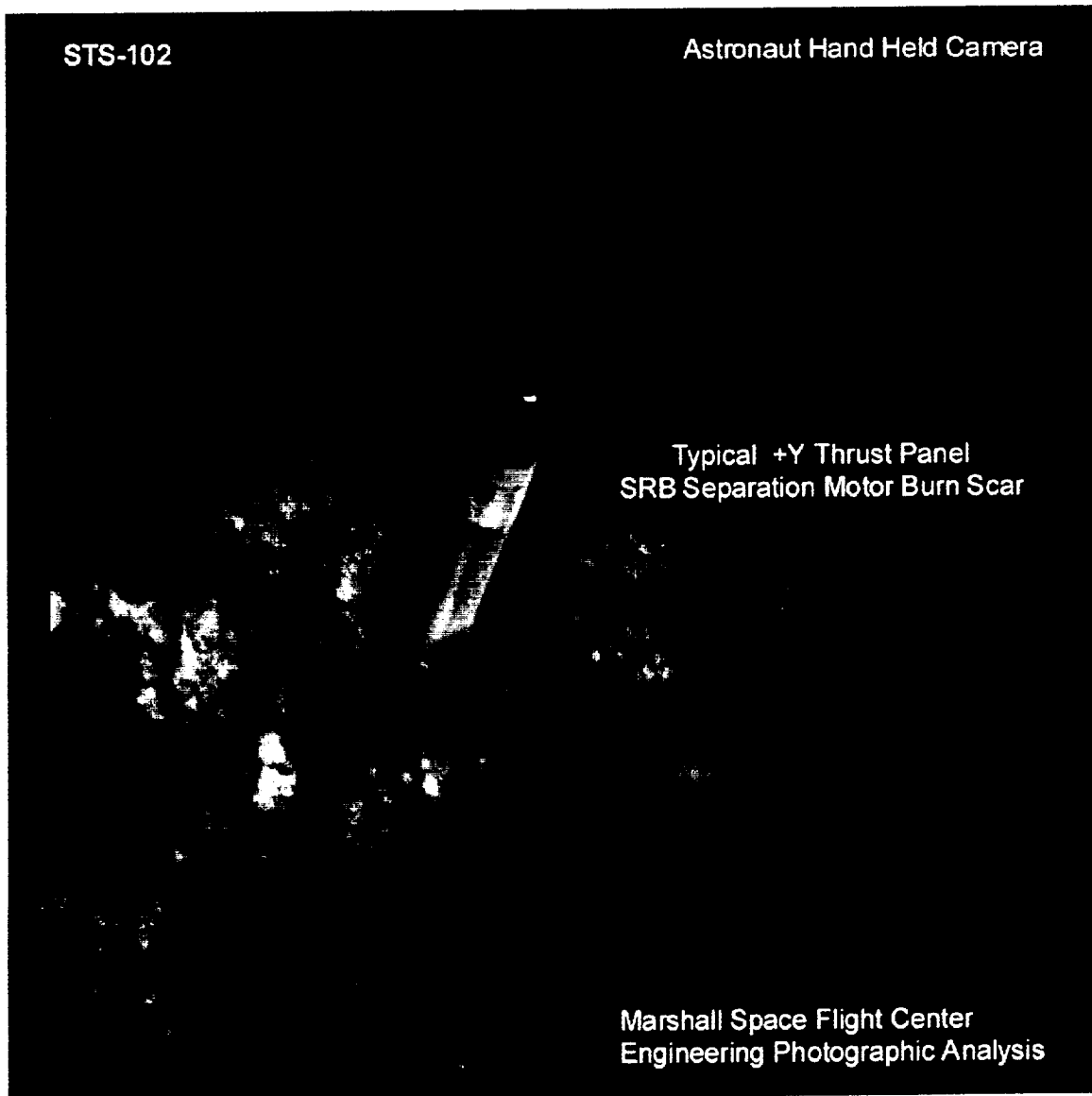


**Figure 16. Protruding EO-3 Interface Bolt**

***Astronaut Hand Held Video Camera: External Tank +Y Thrust Panel***

Typical aeroheating on the nose TPS and burn scars from the SRB separation motors on the intertank were noted on the External Tank +Y and -Y Thrust Panels.

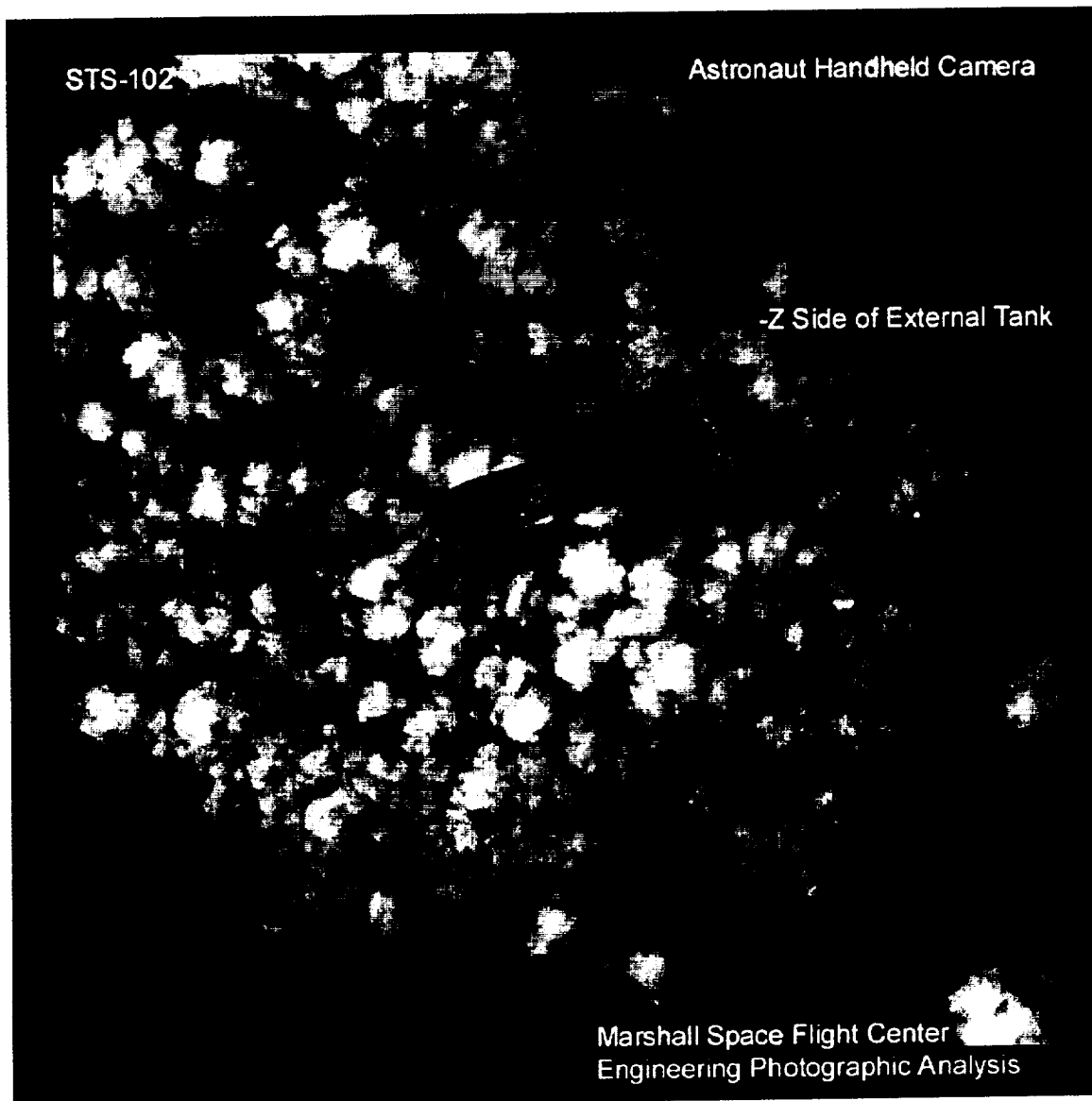
No substantial divoting could be discerned on the ET TPS and no venting from the ET was noted on the handheld video.



**Figure 17. External Tank +Y Thrust Panel**

***Astronaut Hand Held Video Camera: External Tank -Z Side***

Typical aeroheating of the nose TPS was observed on the -Z side of the External Tank TPS.



**Figure 18. External Tank -Z Side**

## Individual Camera Assessments:

Assessments for individual cameras are listed below. The assessments for all individual cameras including camera characteristics as noted in the Photographic Acquisition Disposition Document (PADD) for flight STS-102 may also be found on the website.

### *Video Camera Assessments*

TV13	Glowing debris particles ejected from SRB plume after separation. SRB separation: 067:11:44:13.56 UTC.
TV4B	Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume after separation. SRB separation: 067:11:44:13.54 UTC. Frost observed on ET acreage.
TV7B	Pad debris noted rising and falling. Free burning Hydrogen observed. Frost observed on ET acreage.
ET204	Glowing debris particles ejected from SRB plume after separation. SRB separation: 067:11:44:13.5 UTC. Image focus was soft.
ET207	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume after separation. Debris-induced streaks in SSME plume. Linear optical distortions noted. Flow recirculation noted. Camera focus was soft. Typical body flap motion. Paper-like, flapping material observed at aft edge of right Stinger Pod.
ET212	Glowing debris particles ejected from SRB plume after separation. Debris ejected from SRB plume. Images were in soft focus and somewhat overexposed.
ET213	Pad debris noted rising and falling. Image focus was soft. Free burning Hydrogen observed.
TV21B	Frost observed on ET acreage. Free burning Hydrogen observed.
OTV109	Typical ice/frost from 17-inch disconnects.
OTV141	Free burning Hydrogen observed. Frost observed on ET acreage.
OTV149	Typical ice/frost from LO2 T-0 umbilical.
OTV150	Image overexposed, little engineering value.
OTV151	Free burning Hydrogen observed.
OTV154	Typical ice/frost from 17-inch disconnects. Purge barrier material debris from LH2 17 inch disconnect observed. Typical elevon motion observed.
OTV160	Pad debris noted rising and falling. Frost observed on ET acreage.
OTV161	Frost observed on LOX vent louvers.
OTV163	Typical ice/frost from 17-inch disconnects.
OTV170	Frost observed on ET acreage. Free burning Hydrogen observed.
OTV171	Typical ice/frost from LH2 T-0 umbilical. Free burning Hydrogen rises above OMS Pod.

### *Film Camera Assessments*

E1	Pad debris noted rising and falling. Purge barrier material debris noted. Frost on ET acreage observed.
E2	Streak on SSME#1 plume observed. Free burning Hydrogen observed. Purge barrier material debris noted. Notable amount of SSME#1 drain line vapors observed.
E3	Pad debris noted rising and falling. Free burning Hydrogen observed. Notable vapors from SSME#1 drain line.
E4	Typical ice/frost from LO2 disconnect. Purge barrier material and water baggy material debris noted.
E6	Film received was E42, not E6. GUPC retraction appeared normal.
E7	Pad debris noted rising and falling. Large piece of aft skirt foam breaks free.
E8	Holddown Post M2 PIC firing time at 067:11:42:09.011 UTC. Typical pad debris observed.
E9	Holddown Post M1 PIC firing time at 067:11:42:09.012 UTC. Thread that binds adjacent thermal curtains is visible. O-Ring or washer debris item noted at 067:11:42:09.112 UTC.

- E220 Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Camera loses track of vehicle.
- E222 Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Frost observed on ET acreage. Camera loses track of vehicle momentarily.
- E223 Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Linear optical distortions noted. OMS motor firing observed. Frost on LOX Tank observed. Film processing marks noted.
- E224 Debris-induced streaks in SSME plume. Soft focus.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE May 2001		3. REPORT TYPE AND DATES COVERED
4. TITLE AND SUBTITLE Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-102			5. FUNDING NUMBERS  OMR500U0	
6. AUTHOR(S) Jorge E. Rivera				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA, John F. Kennedy Space Center Process Engineering, Mechanical Systems Division ET/SRB Branch, Mail Code: PH-H Kennedy Space Center, FL 32899			8. PERFORMING ORGANIZATION REPORT NUMBER  NASA/TM-2001-210257	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Blanket Release			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-102. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch were analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the debris/ice/thermal protection system conditions and integrated photographic analysis of Space Shuttle mission STS-102 and the resulting effect on the Space Shuttle Program.				
14. SUBJECT TERMS SUBJECT CATEGORY: 115, 16 STS-102 Thermal Protection System (TPS) Ice Debris Photographic Analysis			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE  Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT  Unclassified	20. LIMITATION OF ABSTRACT  Unlimited	